COMMUNICATION NETWORK ANALYSIS TO COMPARE BIM AND NON-BIM APPROACHES IN THE AEC INDUSTRY

A Thesis

by

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ABSTRACT

Building Information Modelling (BIM) has been established as standard in the Architecture Engineering & Construction (AEC) industry. The ubiquity of the platform has significantly changed the way AEC industry works. BIM is finding its utility in almost every aspect of the AEC industry. Thus, with such significant level of adoption, the industry is undergoing a significant change adoption process. The introduction of a new Information Technology (IT) platform that has significantly changed the workflow has significant far-reaching impacts. This research aims to study the impact of usage of BIM in the AEC industry on the communication network. The network created based on real-world information is used to perform Social Network Analysis (SNA). The research presents a process to extract real-world information and classify the collected data through text clustering to create project wise networks. Analyzed in this manner, BIM and Non- BIM projects are compared based on network properties to identify the impact of usage of BIM on communication networks. The research found that there is a difference in network properties for BIM and non-BIM projects based on collected real-world data. The properties indicate that the communication network for BIM projects are relatively better in comparison to non-BIM projects. The research identifies the utility of such real-time social network analysis in project management at an executive level.

DEDICATION

I would like to dedicate this thesis to all the people who have invested in me in any form at any point in my life. Without their help, I would not have gained the requisite strength, dedication and will to do things, which I could do.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Professor Eric Jing Du (Chair of the committee) of the Department of Construction Science, Professor Sarel Lavy (Co-Chair of the committee) of the Department of Construction Science and Professor Wei Yan of the Department of Architecture.

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1. INTRODUCTION AND BACKGROUND

Building Information Modelling (BIM) is one of the technologies that are gaining strength. Significant advancements have happened in BIM over the past years, and now BIM has become one of the primary sources of information for other relevant technologies related to Architecture, Engineering and Construction (AEC) industry. Several tools, which are related to different phases of the building are being developed. These tools and applications utilize the information derived from BIM for simplifying the process. Such a significant database of information has helped formulate the designing, costing, scheduling and facility management process. Thus, BIM is involved in all the phases of the building from pre-construction to facility management. The development up to 7D of BIM has covered vital aspects and phases of building. Thus, from a technical perspective BIM is the cornerstone for the AEC industry. BIM is formulated to contain all the relevant source of information which can be utilized for different phases of the project as per the requirements.

Apart from the technical benefits and ease of operation, BIM process has a significant impact on communication within the industry. The communication network within any industry forms the essential core. An efficient communication network can substantially help in the execution of work and increase the overall efficiency. Specifically, AEC industry is primarily composed of individual companies. The AEC project execution is fabricated in a manner that an entire project has many stakeholders and contributors. Thus, intercompany interactions come into play during the design and execution of the project (Malisiovas and Song 2014). Thus, it is of importance to analyze the communication networks, within the company and during the inter-company interactions. Such analysis would lead to key factors

that define the network (Chinowsky et al. 2009). A roadmap which helps to organize such key factors will substantially contribute to increasing the efficiency and productivity. The impact of BIM regarding communication has not been evaluated on practical projects. Study of the quantifiable impact of BIM on the communication network within the AEC industry can help to support the implementation of BIM. Also, a strategy that can help to figure out possible improvements that can improve communication in projects that use BIM can assist the industry.

2. PROBLEM AND RESEARCH OBJECTIVES

2.1 Problem Statement

The impact of the usage of BIM on the communication network in the AEC industry has not been well understood. An investigation into the mechanism about how BIM improves the communication for a given project can help to understand the benefits of using BIM in the AEC industry.

2.2 Research Objectives

To address the problem, the objectives of this research are as below

1) Investigate communication patterns at the individual level in the AEC industry- To gain an understanding of the communication pattern with respect to different stakeholders in the project, an investigative study will be performed. This will help to understand the features of the communication network in the AEC industry. An in depth understanding of the communication patterns will help to perform analysis of the communication network. Relevant data related to the study will be collected.
2) Analyze the efficiency and robustness of the communication network in the AEC industry - Based on investigative study, the understanding of communication network in the AEC industry will be utilized to analyze the properties of the communication network. An analysis of the network will help to determine the parameters that define the efficiency and robustness of the communication network.
3) Explore the benefits of using BIM in AEC projects- With understanding of the analysis of the communication network, the network properties of BIM and non- BIM

project will be compared. Consequently, the benefits of using BIM in the AEC industry will be investigated.

2.3 Research questions

Based on the research objectives the research questions are as under:

1) Is there any significant difference between the communication network of a BIM and a non-BIM project?
2) What parameters of social network analysis reflect the differences?
3) How can we quantify the benefits of using BIM with the help of social network analysis (SNA) in AEC industry?

2.4 Research hypotheses

The research hypotheses are as follows-

1) There is a significant difference in the communication network properties of a BIM and a non- BIM project.
2) Use of BIM facilitates communication in a project and helps to increase the efficiency of communication.

2.5 Assumptions

The assumptions for this research are as follows-

1) With the use of information technology in construction, there are various other modes of interaction between the team members over different platforms. Such interactions are ancillary to email conversations. Thus, IT based communication forms the core of communication in the industry.

2) BIM projects and non- BIM projects to be studied are comparable in project delivery, workflow and scale. Hence, the differences in communication network properties are quantifiable.
3) In IT based communication, the frequency of communication represents the strength of communication network between the nodes.

2.6 Definitions

Average shortest path- It is the average of the shortest paths between all pairs of nodes. A network with low average shortest path tends to have better overall communication since it is able to transmit information in an accurate and timely manner (Malisiovas and Song 2014).

Betweenness- It is the measure of amount of information that passes through an individual node. This property can help to evaluate the bottlenecks in a given network (Malisiovas and Song 2014).

Building Information Modelling- The information management process throughout the lifecycle of a building which focuses on collaborative use of semantically rich 3D Building Information Models (Isikdag and Underwood 2010).

Centrality- Centrality refers to the "importance" or "influence" (in a variety of senses) of a particular node (or group) within a network. It is the measure of distribution of relationship through the network (Chinowsky et al. 2008).

Distance- It is the measure of the total number of connections that must be traversed to reach from one node to another (Chinowsky et al. 2008).

Density - It is the proportion of existing connection between nodes with respect to the number of potential links that can exist if all the nodes were connected through links (Chinowsky et al. 2008).

Modularity- It is the measure of the strength of division of a network when divided in modules. A high modularity network has dense connections with the modules but sparse connections with nodes in a different module (Malisiovas and Song 2014).

Social Network Analysis- Social network analysis is motivated by a structural intuition based on ties linking social actors. It is grounded in systematic empirical data, draws heavily on graphic imagery, and relies on the use of mathematical and/or computational models (Freeman 2004).

3. LITERATURE STUDY

To compare and contrast the benefits of BIM vs. Non- BIM approach, firstly, it is important to understand the benefits of BIM. It is important to understand the assessments which have already been done by researchers. These assessments form the background of our research.

3.1 Building information modelling (BIM)

Researchers have assessed the benefits of BIM in several ways. To evaluate the utility of BIM, it is important to ascertain the areas where BIM is being used by the companies. In this direction, Kreider et al. (2010) assessed the impact of implementation of BIM on the entire life cycle of a project. It was found that 3D coordination is the area where BIM is mostly used for and has the maximum benefit. The criteria for determining the level of BIM implementation during various phases of the life cycle of the project have also been defined in this research.

Key approaches that have been used by researchers are the impact of BIM on the life cycle of the project, the assessment of results through metrics dependent on change orders, request for information (RFI) and project duration, Bryde et al. (2013) has presented a method to analyze the benefits of BIM. In this research, the researchers have used secondary data. The source of the data is through published journals content. The data thus collected for individual projects was analyzed and assessed whether it met the required criteria. Because of this assessment, it was found that BIM helped to reduce the cost and increased control over the life cycle of the project. The effect on communication through BIM were found to be positive in this research. This assessment provides us with the required hypothesis for our

research. Barlish and Sullivan (2012) presented a method to define the value of implementation of BIM. This research helps to clarify the mixed perspectives and benefits of BIM. The result metrics for this assessment in this research were change orders, RFI and duration improvements. The research aimed to compare similar BIM and Non- BIM projects. The outcome of this research stated the high potential for returns by implementing BIM in projects.

The other way of assessment was to monitor the time effort relationship comparison between BIM and Non- BIM project. Lu et al. (2015) aimed to analyze the impact of BIM with the help of comparison of time-effort analysis. It was found that BIM projects had higher initial effort input but contributed to recovering the cost during the later phase of the project. Over the entire life cycle, BIM process had a net cost saving. The curve of time effort analysis is helpful in determining the fee structure for the different phases of the project. As a possible impact of implementation of BIM, the collaboration between the team member increases. Azhar (2011) in the research about the potential benefits and impact of BIM stated that BIM has the potential to enhance collaboration with the participating team members. Thus, it will eventually lead to reduced costs and enhanced efficiency.

Researchers aimed to find out the reason that BIM is not being utilized fully by all the companies though adequate benefits of using BIM have been stated. Linderoth (2010) the research aims at focusing on the reason that has constrained the adoption of BIM in the profession even though the benefits are well known and addressed. The main reason stated in this research is the disruptive nature of the projects. On the contrary adoption of BIM requires long-term thinking. Thus, this contrasting situation is an obstacle to the adoption of BIM. Luth et al. (2013) stated the BIM implementation process is not being utilized to its full

potential. As a result, the maximum possible benefits are not realized. The research supported the fact that BIM implementation should be done up to the fabrication level. This will help to improve the benefits and returns of the implementation of BIM. The research by Cidik et al. (2013) discusses the difference between the technical aspect and human aspect that acts as a hindrance to the adoption of BIM. The research suggests that individuals within the project are at times confused by the role they play and thus the collaboration is held back as a result of it.

In this study, the aim of our research is to understand the impact of BIM on communication pattern within the organization. To analyze the communication pattern, one of the viable method using social network analysis. The need for such an approach is to understand the flow of information within the project. The assessment of the impact of BIM on communication pattern is a certain value addition to the benefits of utilization of BIM in AEC industry.

3.2 Project Communication and Social Network Analysis

Within a construction project, information is exceptionally diverse given the huge number of parties involved. AEC industry projects are classified under complex structures (Yongkui and Yujie 2009) because of the dynamic and unpredictable circumstances. The construction project is a team activity. It requires the involvement of several sub-contractors and specialists to produce the required project outcome. Since people play an important role in communication, application of social science research method is required to understand the roles of people in the construction industry (Toole 2006). Various researches have been done to understand different scenarios. One of the viable methods to perform such analysis is to form a graphical representation i.e. Social Network Analysis (Pryke 2004). Pajek, a social

network analysis theorem (Dohleman 2006) is employed in identifying features of the social network in the construction industry. Such an analysis helps to identify the key members of a construction project (Wambeke et al. 2011). Application of social network analysis to construction projects allows understanding of the actual management structures in an organization(Lin 2014). Social Network Analysis (SNA) presents the communication information in the form of mathematical models. The application of network theory and related software helps to represent knowledge transfer, communication, and trust (Taylor and Bernstein 2009).

Research performed by Chinowsky et al. (2008) indicated the use of SNA to form high-performance teams. The research states that returns generated by resource optimization have reached its optimum level. To achieve better results, the focus of management should be on the project network. Classic project management techniques in combination with social network study can help to increase the efficiency of knowledge transfer within the organization. Such a combination will help to form high-performance teams. Another research by Chinowsky et al. (2009) builds on similar lines. Apart from traditional methods, it aims to focus on trust and efficient communication. Such research presents the efficacy of usage of SNA to understand the factors which are otherwise not outlined. The study emphasizes the approach for reconfiguring team in a way to improve performance. It aims at integrating classic project management techniques with social science variables that can help to increase knowledge and lead to the formulation of high-performance teams and produce improved results. In the analysis of complex project organization Yongkui and Yujie (2009) studied the social relationship aspect of the project in unpredictable and dynamic industries such as AEC and Aeronautics & Astronautics. Researchers have recommended that social

network analysis should be regarded as the basic methodology for complex project management.

Studies have also been performed to understand the spread of information in construction projects. The objective of research performed by Malisiovas and Song (2014) was to develop strategies for resolving initial stage communication problems. The focus of the research was to resolve early stage communications issues by focusing on team structure and information diffusion. SNA was used as a tool to understand the flow of information. A model by survey and interview was developed. The model reflects the participant interaction which was used to analyze possible problems. Later SNA model was used to simulating participants' interaction and analyze potential communication problems. This research helped to optimize team structure in order to have better information flow. Thus, the research studies the communication network in the early phase of the project with the help of social network analysis and finally presents recommendations to rectify the concerns. Studies also aim to understand teamwork and effective order enforcement. The study done by Lin (2014) aimed to discover the underlying job-site management problems by analyzing three job-site social networks, order management, technical -consultation, and interpersonal social networks. As an outcome, it was found that the order-management network has the highest degree of social density. The interpersonal-social network was found to be the least dense with a highly-disjointed structure. With a different type of network structure, different individuals hold importance. In order management networks, site manager and principal engineers assigned are central figures; however, they become outliers in the interpersonal social network. Thus, the study aims at understanding the variation in communication network within the company in different scenarios.

Study by Wambeke et al. (2011) focuses specifically on analysis of the construction phase of the project. In this study, a real-world project was analyzed through social network analysis. The different trades involved in the construction phase are mapped for each week. Thus, the entire construction phase is covered. The interdependency between trades is determined by analyzing the information flow within the project. This is depicted in the form of a matrix. The matrix is utilized to find out the key relevant factors that determine the qualities of the social network. This research is helpful for project managers as it helps to determine the key trades involves in the construction project through spatial proximity. Study done by Park et al. (2010) aims at the usage of SNA to analyze collaborative ventures for an overseas construction project. The research investigates the collaborative networks for performing international projects. The research outcome draws the finding with respect to the difference in tactic between large companies (LC) and small and medium-sized companies (SMC) while making collaboration relations. This study aims to understand the relevant network patterns and access the performance with respect to different network attributes. This study presents a method to achieve better outcomes while taking in into consideration the various performance attributes of the network.

3.3 Relevant Works (Point of departure for our research work)

Research by Al Hattab and Hamzeh (2013) compares the information flow between traditional and BIM based projects for the design phase of the building. The interaction between various members of the project is represented using the information flow (swine-line diagram). The research supported that with the help of Building Information Modelling the flow of information is streamlined. Our research can contribute to replicate the information flow diagram presented in this research. As a future work, this research suggested to simulate

the information flow. This research is limited to design phase of the project. Thus, our research can help to add knowledge to the domain. Research by Al Hattab and Hamzeh (2015) aims at utilizing social network analysis to compare two different processes, i.e. traditional versus BIM- lean practice. This research substantiates our approach of comparing the utility of social network analysis for comparing traditional versus other technology. This lays foundation for our research. In this research, the design error management aspect is studied by comparing the social network structure. In this study, the dynamic side of the network structure is investigated with the help of NetLogo software and for static analysis, Gephi is utilized. The basic parameters for comparing different social networks are defined in this research. The research has parallels with our research but has been performed for the design phase of the building. It is based on the hypothetical representation of the network. This hypothetical model is formulated based on literature study.

In our research, we are building the communication model based on real world information. Such an approach will help to fill in the research-gap by using real world information. To build the network, email communication as the basis for forming the network. This approach has been used by Dogan et al. (2013) in their research to understand the coordination using email network. Also, the use of real world inputs can contribute to validate the theoretical models for different phases of the project. Thus, SNA has been employed at various levels to identify different properties of communication networks in AEC industry. Social Network Analysis finds its relevance in identifying communication network properties which are otherwise not well defined.

4. METHODOLOGY

Table 1 Methodology steps based on research objectives

Research Objective -1	Research Objective -2	Research Objective -3
Investigate communication patterns at an individual's level in AEC industry	Analyze the efficiency and robustness of the communication network in the AEC industry	Explore the benefits of using Building information modelling in AEC projects
Step 1& 2	Step 3	Step 4
Literature review and data collection through quantitative data collection.	Social Network Analysis to determine the properties that define the robustness and efficiency of the network.	Comparative study based on network metrics to highlight the difference between BIM and non- BIM projects

To achieve the stated research objectives, the following the research methodology was followed.

1) To investigate the communication pattern at an individual level in a project, the literature review was done to understand the key parameters that can help to understand the communication network features. The keywords under which this study was performed were, "BIM", "SNA", information flow in AEC, organization representation. Performed in this manner, recent developments in research were studied. Key databases under engineering and sociology field were searched to determine the relevant literature study and recent

developments. Databases such as ASCE Library, ProQuest, SocINDEX were helpful in this study. Such an investigation helped to develop a broader understanding of the topic.

A pilot study was conducted. The objective of this pilot study was to validate the process of depicting IT based communication using social network. For this pilot, researchers' personal email log was used. This email log was used as an input for the social network analysis software, Gephi Thus the email log was depicted in terms of social network (Fig. 1a). An initial analysis of the network thus derived was performed. With the help of analysis, the major contributors in the communication were identified (Fig. 1b). Also, the subgroups present in the network were identified with the help of social network analysis algorithms supported by the software (Fig. 1c). The network properties such as centrality, node- distance were also determined. The outcome dervied from the analysis were validated. An important part of this research is to collect real-world data.

(a) (b) (c)

Figure 1 Social Network generated with the help of email log using Gephi Software

2) To determine the properties of the network under study, the communication network of the projects was formulated based on real world data with the help of email log using social network analysis software, Gephi. The participating companies were approached. Given the

nature of research which requires the usage of BIM in the construction process and to make a valid deduction, comparability of projects is an important parameter, hence a selected set of AEC companies qualified the criteria. The research was explained to them with the help of explanatory videos and during conversations. Following it, a discussion to understand the project type, project scale and usage of BIM was done. The requirements of comparability of projects such as project delivery, project type and scale were explained to the companies. Based on the requirements, the participating companies' key personals were asked to select projects that were comparable. As discussed in the literature study, email log has been used by researchers to formulate communication networks to understand the social network parameters (Dogan et al. 2013). Thus, to be able to formulate unbiased social networks, for data, we used IT based communication channel (email conversation logs). The reason to use IT-based communication channel is that it reflects the formal conversation between the team members. This data helped us to quantify the interaction between the individuals. This approach ensured that the model created with the help of these inputs reflects the closest possible realistic communication network within a project. To collect data, researchers received IRB approval. Thus, the email log collected from the companies was used to formulate the communication network.

3) To determine the properties that can help to quantify the robustness and efficiency of the network, Social Network Analysis was done. The collected data was fed into a social network analysis software, Gephi. The application has the capabilities to calculate the network properties that can be used to analyze the communication networks. This application has been used by other researchers in similar studies and they have found it to be an efficient tool for analyzing the pattern of communication. With the help of this application, the

mathematical properties of the network were determined. As identified from the literature study, the relevant properties that are used for comparing communication networks are Structure metrics, Node metrics, and Network metrics. Structure metrics include the study of the properties such as the number of nodes, number of edges and graph type. Node metrics include analysis of the degree of centrality, betweenness, and closeness. Network metrics include density, avg. path length, diameter, modularity and number of subgroups.

4) To perform comparison studies to find the difference between a BIM and a non- BIM project, an analysis of the network metrics was used to quantify the network properties. These properties were quantitatively analyzed and compared between BIM and non- BIM approach to explore and quantify the benefits of using BIM on communication network in AEC industry. A structured quantitative analysis was performed.

5. FINDINGS

With the help of VBA script the participating companies extracted the email log. A description of the collected data is as follows-

Table 2 Description of Collected data

Total Email log received	~50000
Number of participating companies	4
Total number of projects studied	22
BIM projects	13
Non- BIM projects	9

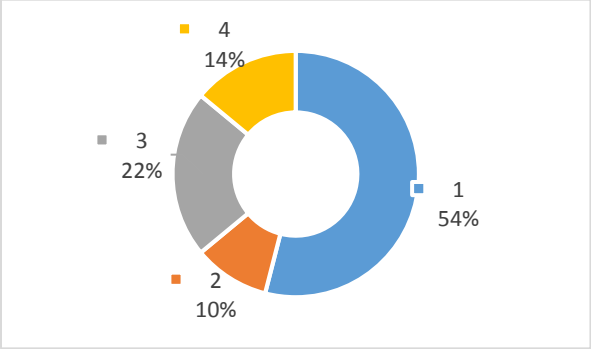


Figure 2 Percentage distribution of email log received per participant company

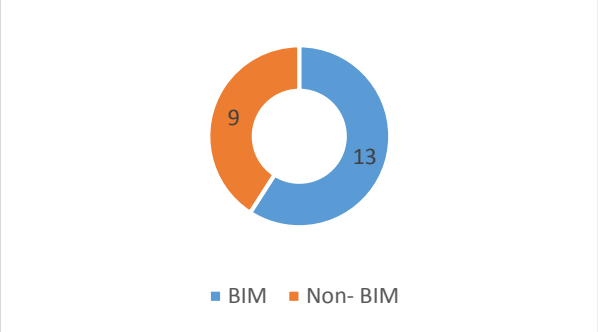


Figure 3 Percentage of BIM and Non-BIM projects as a total of all the projects

The following steps were invloved in the collection of data and analysis.

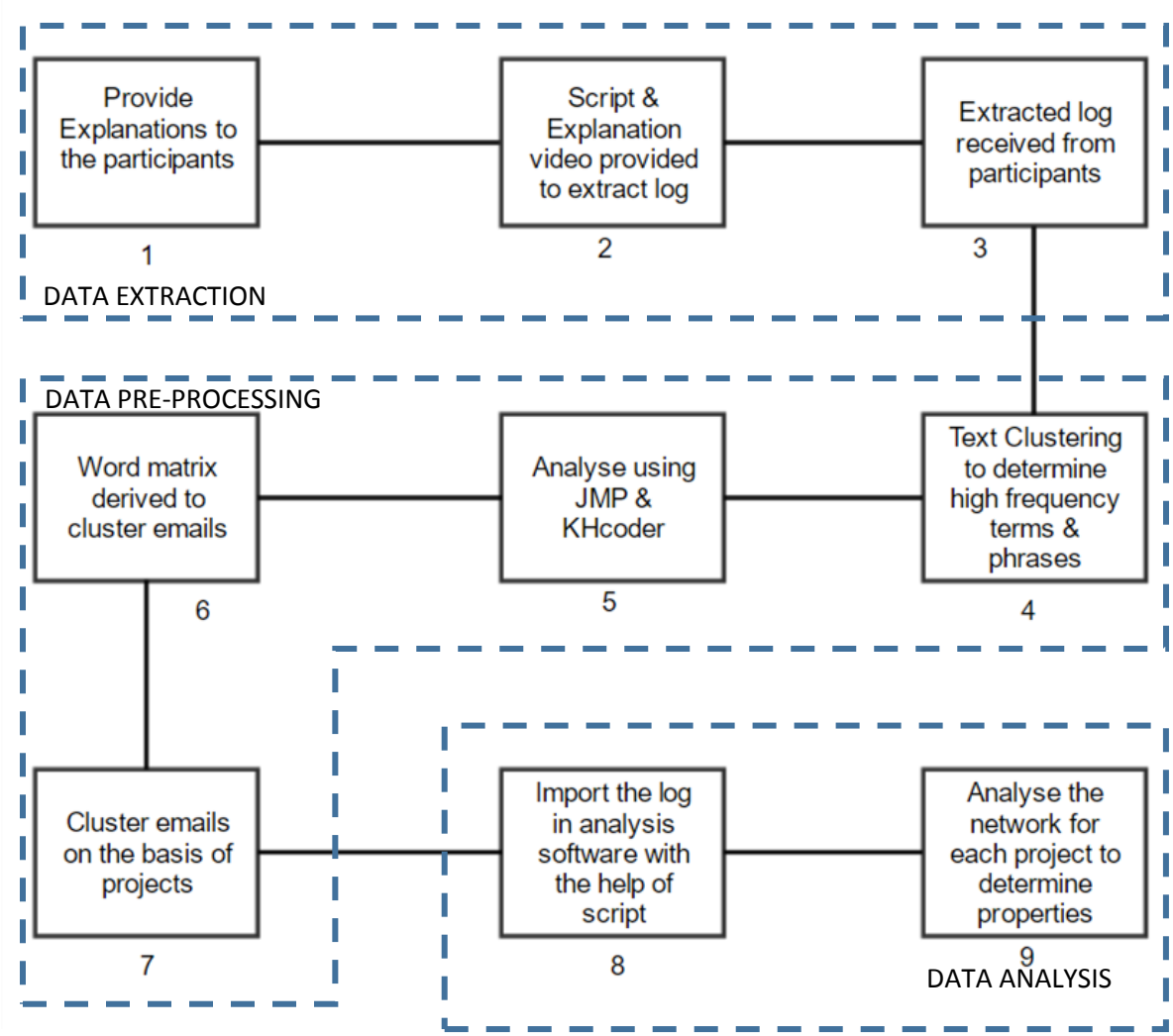


Figure 4 Flowchart to explain the process of extraction of data

a) Research Explanation and data extraction-The stated companies were approached to share the required available data as per the requirements of the study. The key factors that differentiate the projects were explained and the companies were asked to select the projects which meet the criteria's of scale and type of projects. In this research, email network of projects was studied from the point of view of the key participant, for example, coordinators, managers.

In order to collect data, a script was provided to the participants that extract the email log from the outlook folder. This approach helped to extract unbiased information about email log. Explanatory videos were made. These helped to participants to extract the data on their own.

Sharing of personal email log is a critical aspect, hence it is important to gain the confidence of the participants. Few participants were not comfortable with sharing the email log information and hence could not participate in the research.

The extraction of email log with the help of script helped individuals to review the data which they provided. It was instrumental in promoting the participation. After due diligence, the email log for each participant was received.

b) Data pre-processing - There are two different scenarios, the first case in which project wise separated email log was provided by the participants and the second case in which the email log provided had more than one project.

For the case when the email log was projectwise, the data of the log was imported in the network analysis software with the help of plugin that can create multiple connections between the sender, receiver, and Cc.

The second case in which the data log provided consisted of more than one project, a way to segregate email on the project wise basis was required. This was the next key challenge that we faced was the segregation of email on the basis of projects. This challenge was overcome by utilizing text clustering approach. In this approach, the collected subject lines of the email networks were analyzed with the text analysis platforms JMP 13 Pro and KHcoder. For smaller email log bases, KHcoder was successful in performing the email analysis. For larger email log database, JMP 13 pro was used.

A sample for both of the approach follows.

b1) JMP Text clustering- A sample of the text analysis generated is as follows-

Table 3 Text Analysis matrix

Term	Count	Phrase	Count	N
[illegible]	4239	[illegible]	1729	2
[illegible]	3143	[illegible]	1282	2
[illegible]	2622	[illegible]	888	2
[illegible]	2575	[illegible]	733	2
[illegible]	2271	[illegible]	681	2
[illegible]	2131	[illegible]	662	2
[illegible]	2127	[illegible]	636	3
[illegible]	2120	[illegible]	499	2
[illegible]	2007	[illegible]	498	3
[illegible]	1615	[illegible]	495	2
[illegible]	1600	[illegible]	483	2
[illegible]	1571	[illegible]	479	2
[illegible]	1529	[illegible]	468	3
[illegible]	1404	[illegible]	467	4
[illegible]	1371	[illegible]	449	2
[illegible]	1331	[illegible]	428	2

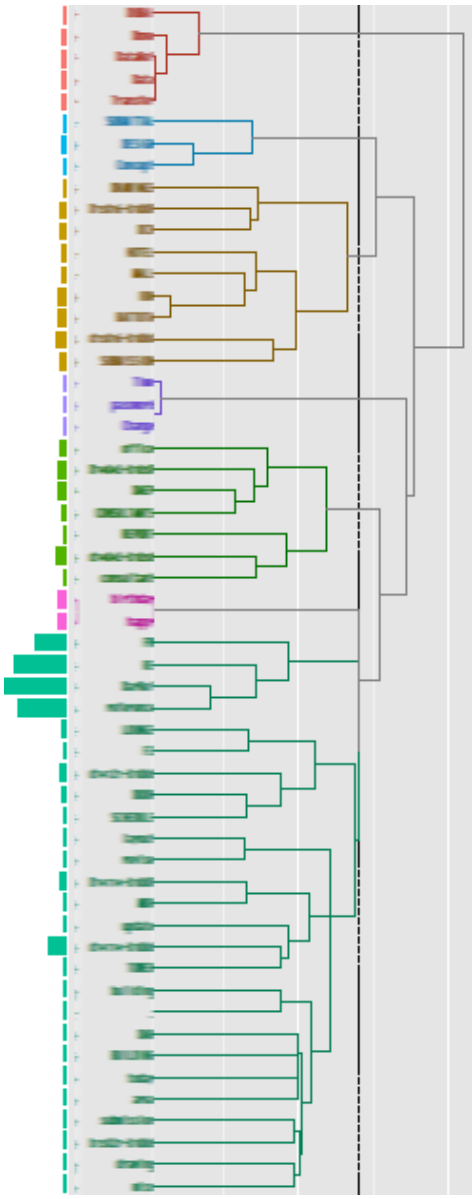
A sample output of the relationship between the text in the subject line based on analysis is shown in the next cluster diagram. Such analysis helped us to segregate the email based on projects. The separate project titles were verified.

The separate cluster formed show semantic relationship found between the words used in the subject lines of the email log. Such clustering helped to segregate the email log based on projects.

Figure 5 Text clustering of the email subject line

Thus, with the help of this analysis segregated email log for each project was created.

b2) Text Clustering KHcoder approach-The second approach is to perform the analysis with the help of KHcoder- A text clustering platform. Using the initial analysis, the frequency of terms is determined. This acts as a pre -screening for understanding the important keywords related to a project. The next step is to perform the text clustering analysis and generate a word occurrence matrix. A representative text analysis outcome is as follows.

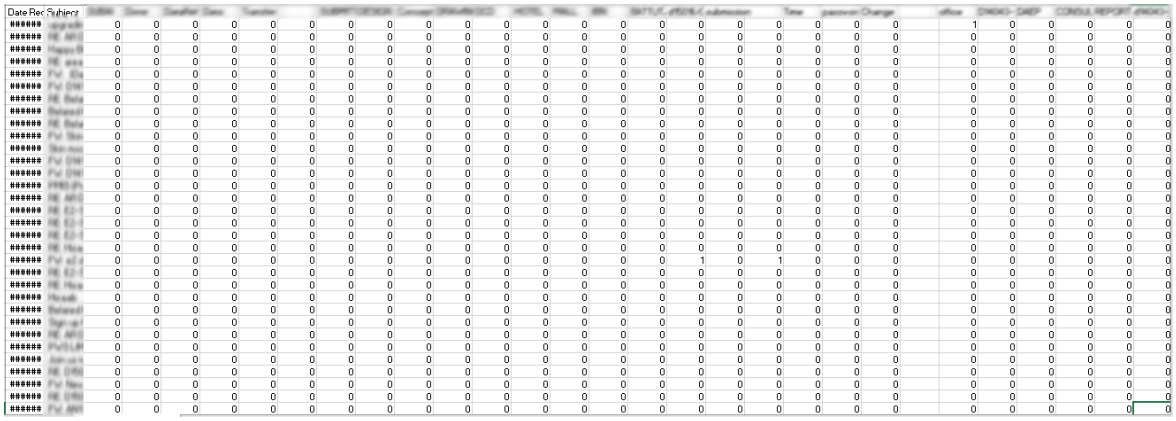


The dendrogram shows relationship between the words that were used in the subject line of the email log. The color coding shows relationship of words related to each project. These relationships are determined by text analysis and represent semantic relationship.

Figure 6 A sample text clustering generated from KHcoder

Such dendrograms (Figure 4 text clustering relationship diagrams) are generated. This shows the relationship between word co-occurrence and hence can be used to segregate the email on the basis of subjects. The word occurrence matrix is extracted from KHcoder. A sample word matrix is as follows.

Table 4 Sample Word co-occurrence matrix

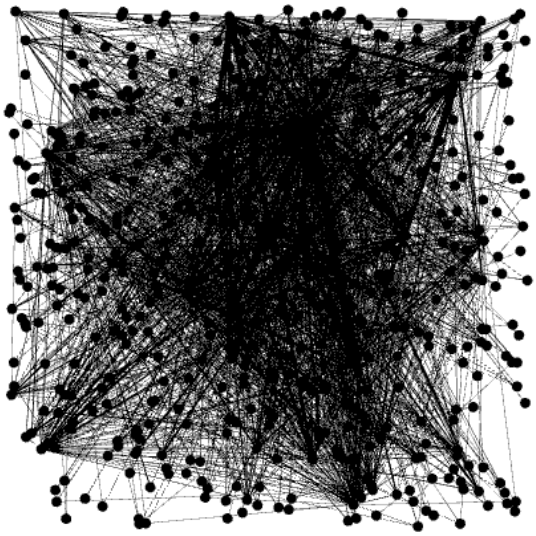


The word matrix shows the occurrence of words in a subject line. The columns in the word occurrence matrix are rearranged as per the text clustering output with the help of a script. Thus, the email log is segregated project wise on the basis of text clustering output by adding up the occurrences count. The clusters are color-coded for each project. Finally, the log data is sorted project wise and separated.

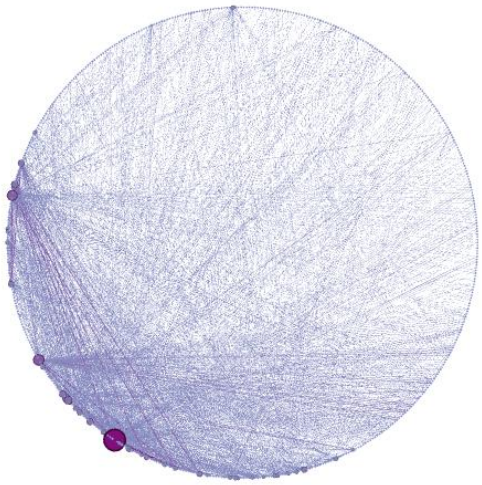
b3) Verification- The project wise email log was verified with the participant. The separate project email log is the input source for the network analysis software. In summary, these programs provide a possible streamlined process for analyzing text. The text statistics for each participant's email log was used to determine the repetitive patterns of text. This was used to extract word matrix for each participant's email log. On the basis of frequency and pattern of text, the email log was clustered. This clustered email log was supervised to remove possible discrepancies. Thus, the separate email log for each project was generated.

C1) Data input to network analysis software-The separate email log for each project was fed into the analysis software, Gephi with the help of import plugin that created the network between the source and targets in an email log. Thus, a total of 22 project communication network were studied under this research. With the help of analysis, on the basis of pre-defined functions in the Gephi platform, the properties were calculated.

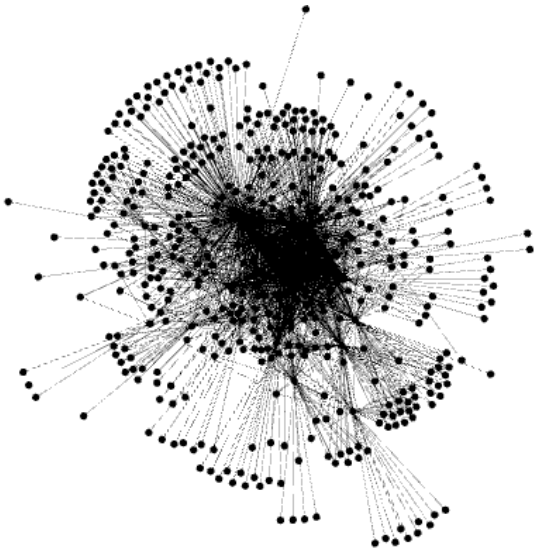
C2) Data Analysis with the help of network analysis platform - In this manner, the social network of the email log of each project was generated with the help of analysis platform, Gephi. Data Mining and social network analysis was conducted on the collected data to determine the properties. An analysis for one of the project follows. A similar analysis was conducted for all the projects. In this research, a total 50,000 email logs were analyzed to reflect real world communication networks. Because of a large number of email log, an automated process is necessary. In our research, we could use a methodology that resolves the issues that proposes an automated process.



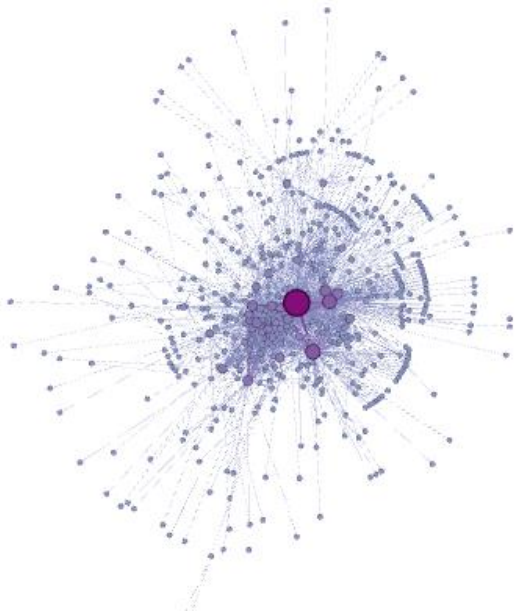
a) Random Layout



b) Circular Layout



c) Yifan hu



d) Yifan Hu Propotional with node sizes

Figure 7 Sample project Network

Figure 7 shows a sample of the network diagrams created with the help of Gephi Software. With the help of network analysis software, the project network properties were calculated. In figure 7a we can see what a network looks like in a random format. Figure 7b shows the network after applying the circular arrangement algorithm. The objective to show the circular arrangement of the network is to understand the small world network properties of a network. Figure 7c Yifan Hu arrangement places the most important nodes at the center of the network while moves the least important nodes away from the center. The algorithm is based on attraction and repulsion between the network nodes. Figure 7d used Yifan Hu proportional with the relative sizing of nodes based on network properties. The edges are also weighed based on the frequency of network connections. Appendix A has a compiled project network diagrams thus formed based on email communication log of projects. Network diagrams are an important way to understand the project dynamics. The network diagrams can be used an important tool to understand the status of the project, contribution of individual members, existing project team structure. In our analysis, we focused our analysis of the network limited to intended research questions. The researchers recommend further research that employs similar real-world data collection and analysis of the network structure and relates it to the project dynamics during the project to determine the changes that reflect project attributes and status objectively. In this research, we focused on network properties to determine and answer of research questions.

Compiled analysis of the network properties follows.

6. ANALYSIS

The in-detail project wise network diagrams can be found in the appendix-A. The network analysis platform helped to determine the key network performance metrics. To understand the network behavior, it is important to understand the scale-free properties. The scale-free properties are independent of the scale of the network and hence can be compared for different sizes of the project. Table 5 shows the compiled statistics. It is recommended to read the properties with the project network diagrams to gain better insight.

Table 5 Compiled Statistics

Projects	BIM/Non-BIM	Number of Nodes	Number of Edges	Graph Type	Degree Centrality	Avg. Weighted Degree	Density	Avg. Clustering Cofficient	Avg. Path Length	Diameter	Modularity
1	BIM	157	311	Undirected	3.962	11.822	0.025	0.59	2.771	6	0.318
2	BIM	655	1223	Undirected	3.734	10.748	0.06	0.442	2.883	8	0.442
3	Non-BIM	37	67	Undirected	3.622	5.351	0.101	0.429	2.222	5	0.242
4	Non-BIM	100	196	Undirected	3.92	10.41	0.04	0.657	2.868	7	0.373
5	BIM	30	84	Undirected	5.6	17.867	0.193	0.712	2.057	3	0.102
6	BIM	72	312	Undirected	8.667	39.806	0.122	0.729	2.165	5	0.122
7	BIM	42	67	Undirected	3.19	6.81	0.078	0.577	3.139	6	0.291
8	BIM	87	249	Undirected	5.724	40.552	0.067	0.767	2.445	5	0.195
9	Non-BIM	138	667	Undirected	9.667	47.188	0.071	0.659	2.432	5	0.186
10	BIM	106	361	Undirected	6.811	40.849	0.065	0.678	2.417	6	0.139
11	BIM	154	236	Undirected	3.065	15.883	0.02	0.543	2.842	5	0.315
12	Partial BIM	189	369	Undirected	3.905	18.91	0.021	0.515	2.886	6	0.411
13	Non-BIM	530	2147	Undirected	8.102	23.66	0.015	0.572	2.523	5	0.277
14	BIM	198	700	Undirected	7.447	39.5	0.04	0.68	2.649	5	0.307
15	Non-BIM	822	2020	Undirected	4.915	12.423	0.006	0.374	3.536	7	0.511
16	BIM	389	1694	Undirected	8.71	52.144	0.033	0.742	2.57	5	0.172
17	BIM	268	1193	Undirected	8.903	36.739	0.033	0.608	2.528	5	0.214
18	Non-BIM	180	438	Undirected	4.867	28.467	0.027	0.365	3.313	7	0.232
19	Non-BIM	153	475	Undirected	6.209	23.634	0.041	0.522	2.7	6	0.186
20	BIM	202	647	Undirected	6.406	57.317	0.032	0.796	2.452	4	0.277
21	Non-BIM	129	239	Undirected	3.705	10.45	0.029	0.348	3.363	8	0.418
22	BIM	139	593	Undirected	8.532	47.065	0.062	0.719	2.33	4	0.209

Stage 1- In this part of the study, we investigated the spread of the properties to understand the relationship. The spread of the properties is as shown in Figure 6. The statistics shown in figure 6 includes all the projects.Following it the properties of Non- BIM projects are discussed separately in Figure 7. Figure 8 shows the properties of BIM projects. The

compiled project types are followed by an individual comparison of properties for BIM and Non-BIM projects.

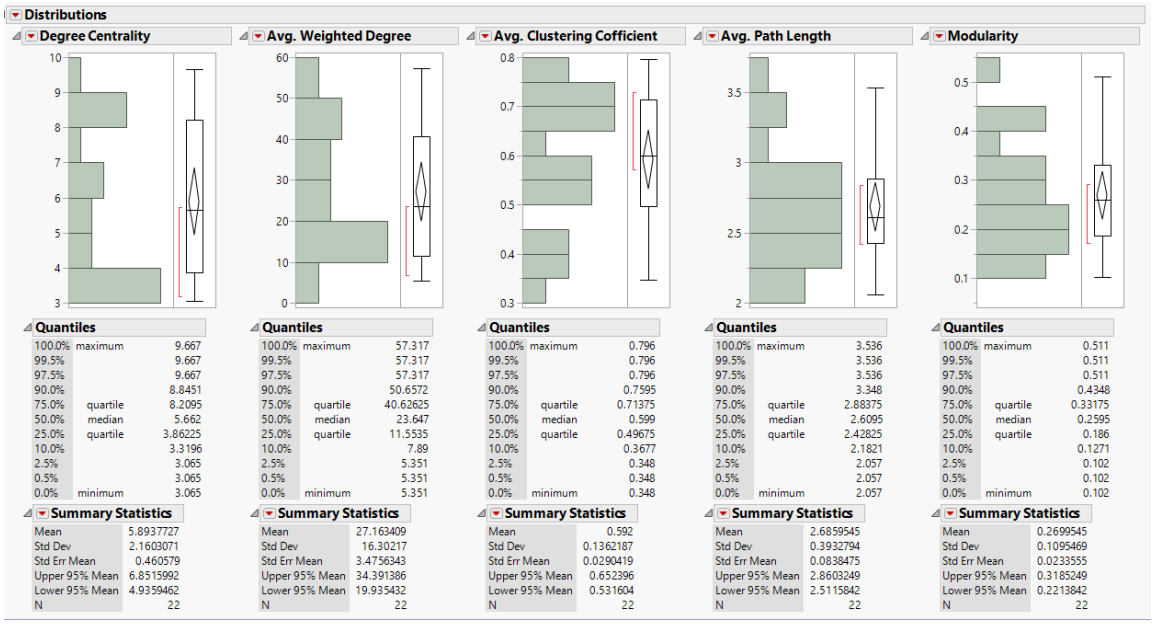


Figure 8 Spread of the network properties

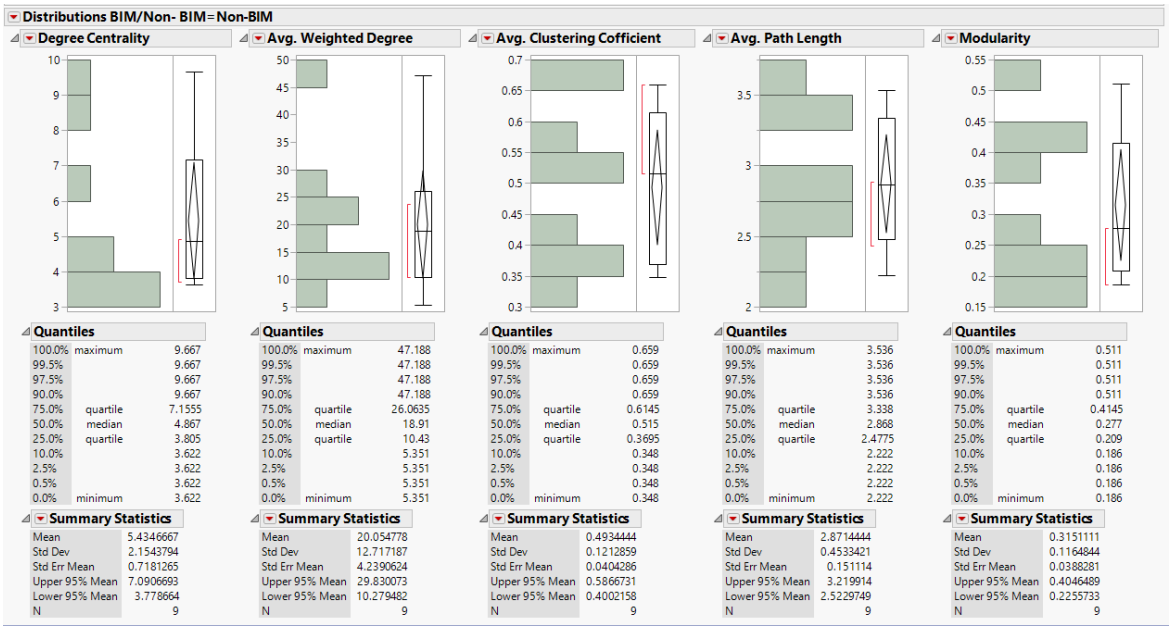


Figure 9 Spread of properties of Non-BIM projects

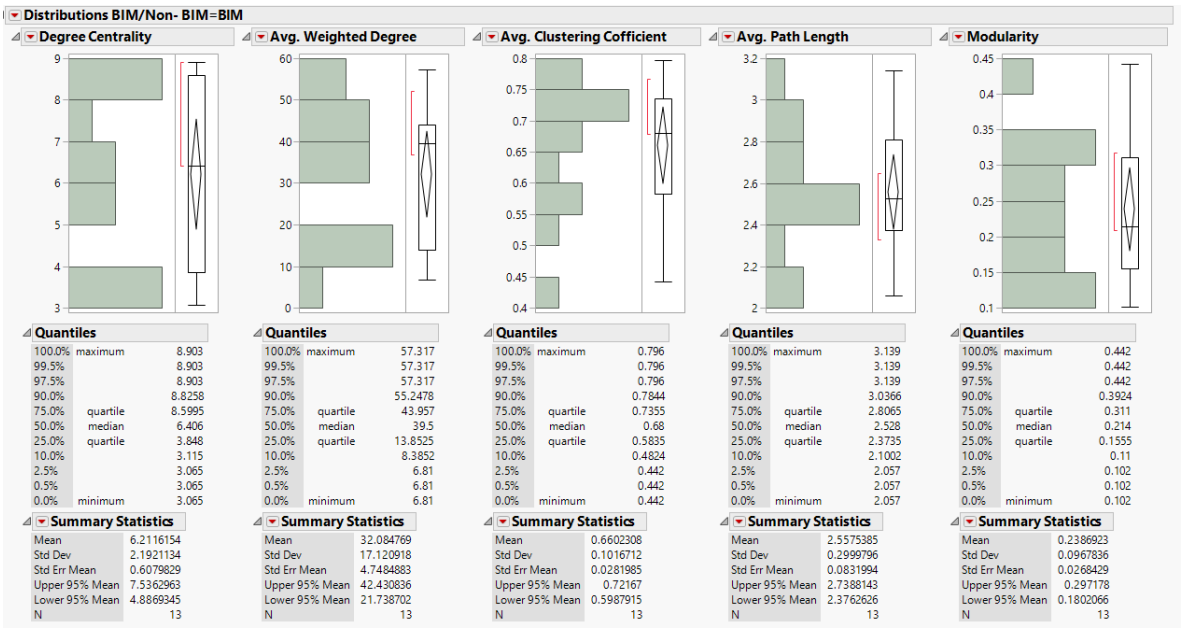


Figure 10 Spread of properties for BIM projects

Stage 2- In order to understand the differences in the properties, comparative tests were performed. Properties of the network were compared for BIM and Non- BIM projects to understand if there are any significant differences that can help to determine the impact. The results of the variability comparisons (ANOVA) follows.

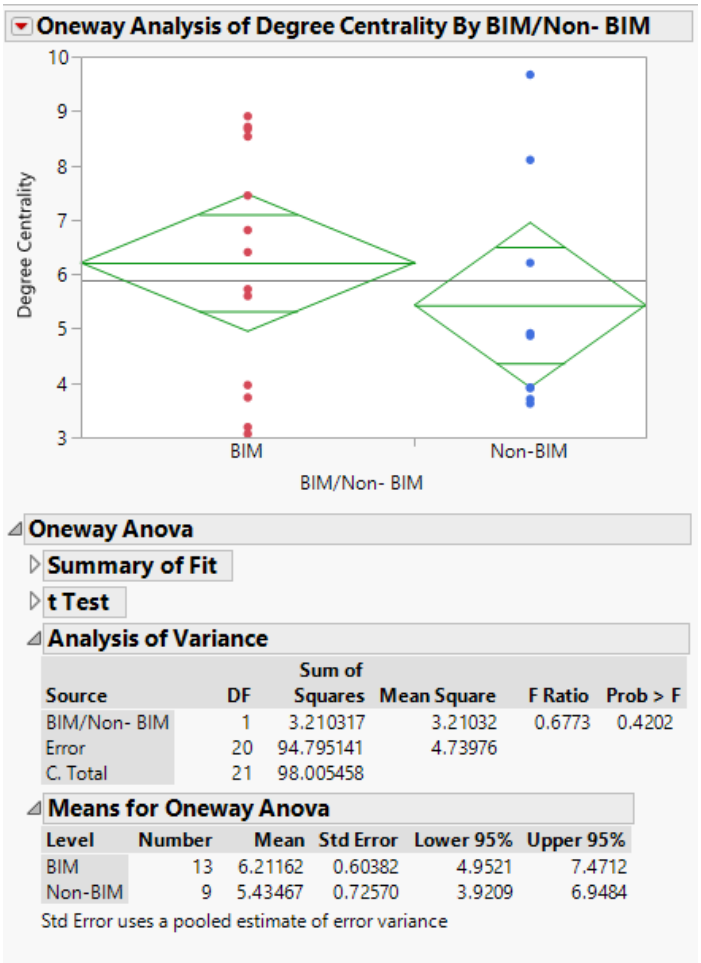


Figure 11 Degree Centrality Comparison

From the comparison, it can be observed that the BIM and Non- BIM projects have shown a high value of p which signifies that the difference between BIM and non-BIM projects cannot be identified on the basis of the degree of centrality property.

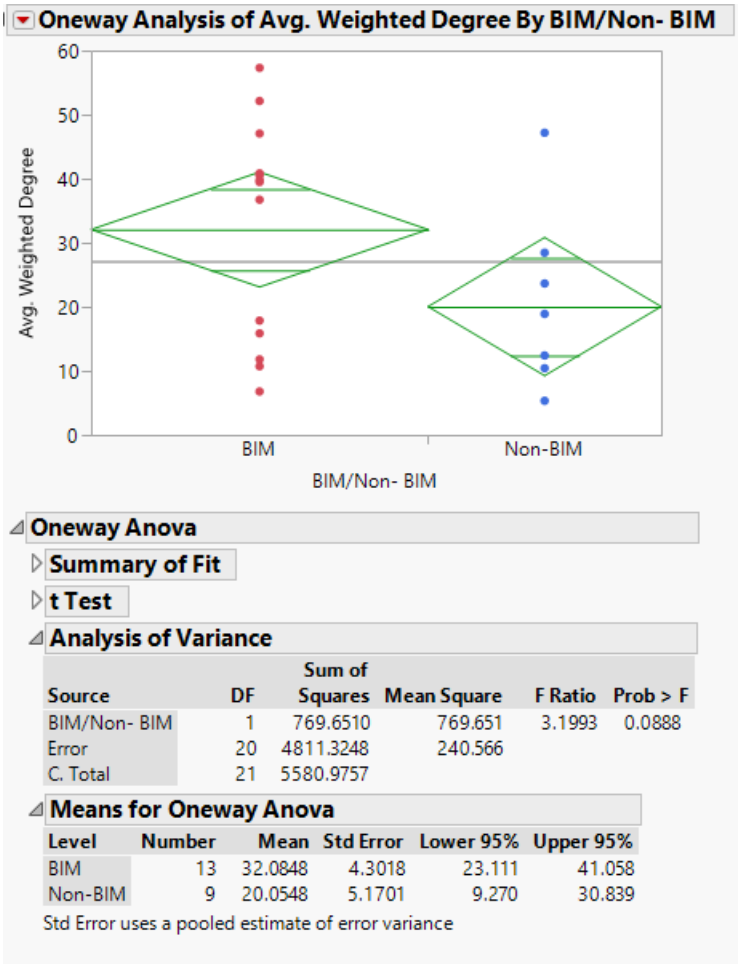


Figure 12 Average Weighted Degree Comparison

Average weighted degree shows a difference with a p value of less than .1 but it more than .05. Hence the average weighted degree has differences on the basis of p-value with a lower degree of certainty.

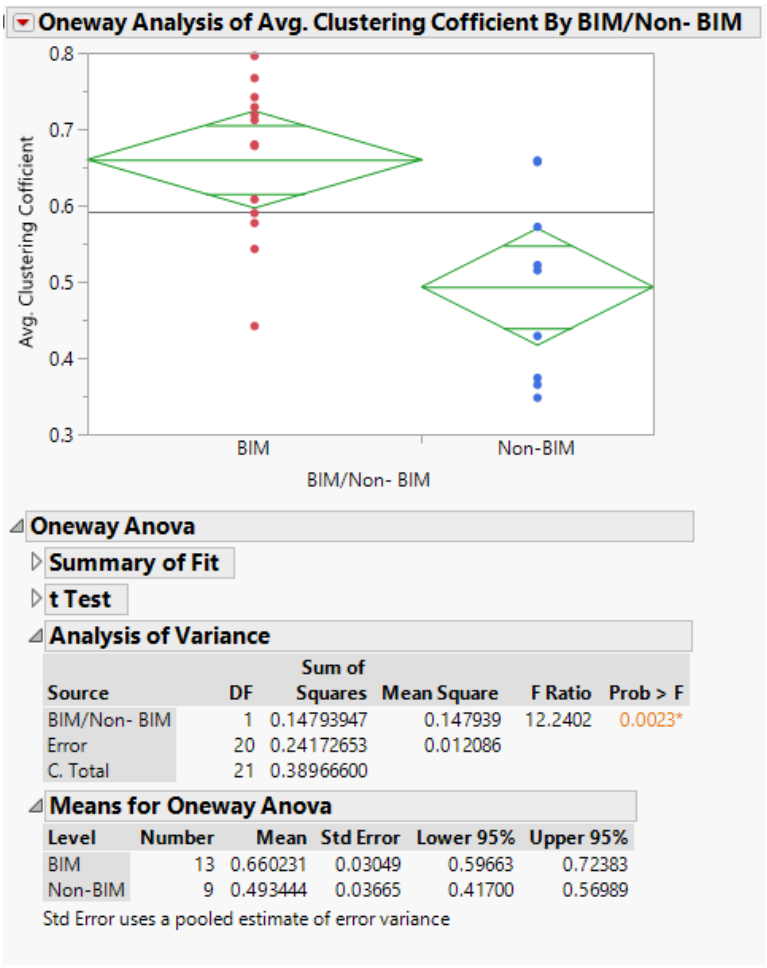


Figure 13 Average Clustering Coefficient Comparison

From the p-value, we can identify that the there is a significant difference between BIM and Non- BIM projects.

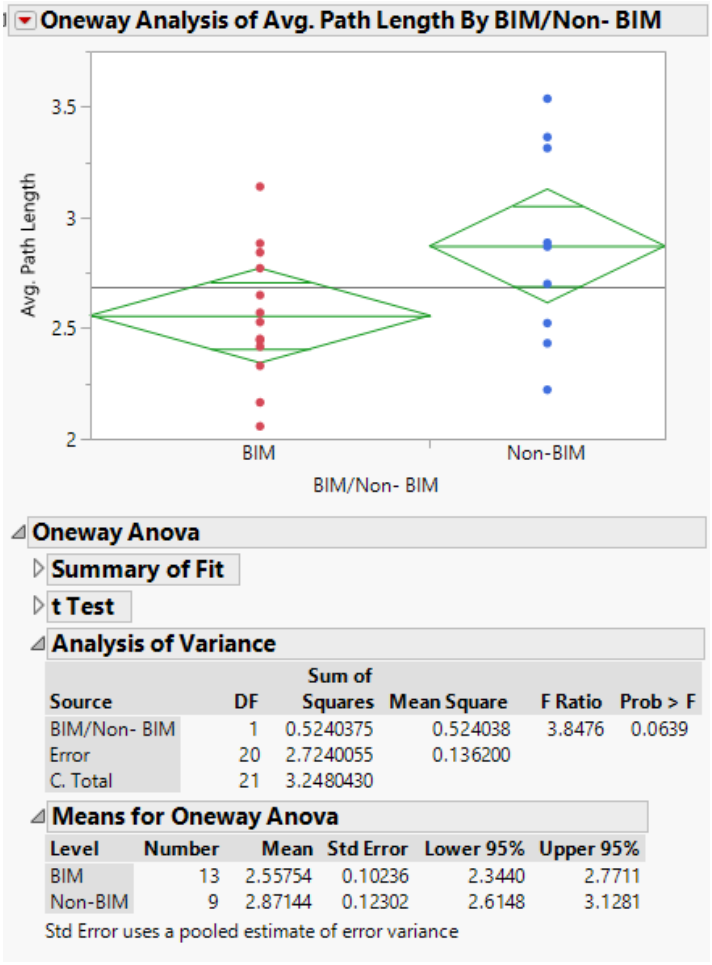


Figure 14 Average Path Length Comparison

The p-value is > .05 but less than <.1. It signifies that there is difference between the BIM and Non- BIM projects with a lower degree of certainty.

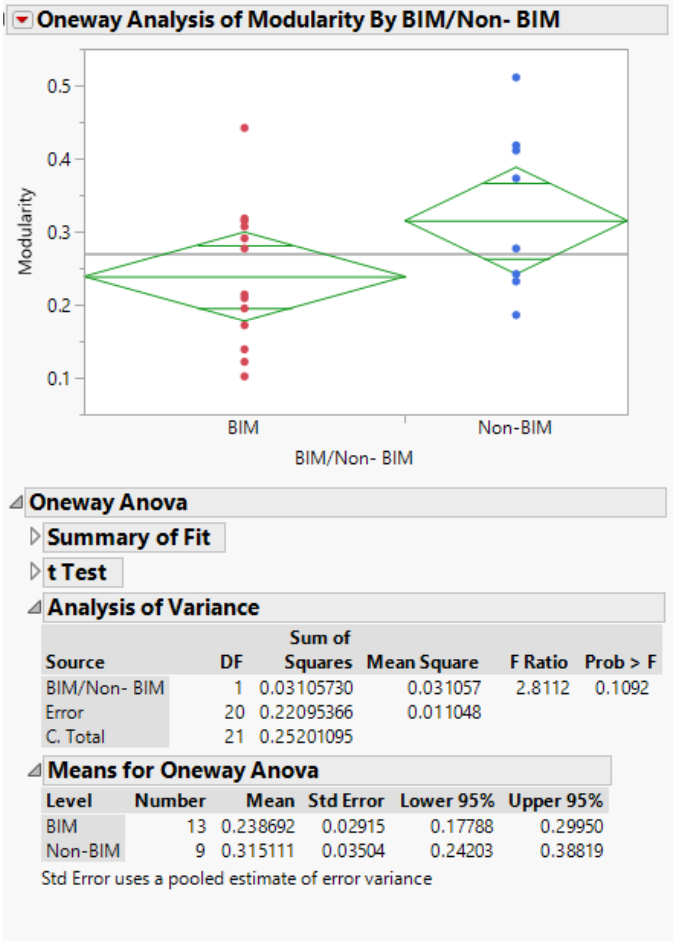


Figure 15 Modularity Comparison

The p-value is >.1 hence the difference between the BIM and non- BIM projects on the basis of modularity property cannot be established with certainty. Figure 17 shows the parallel plot of the properties to understand the variation of these properties.

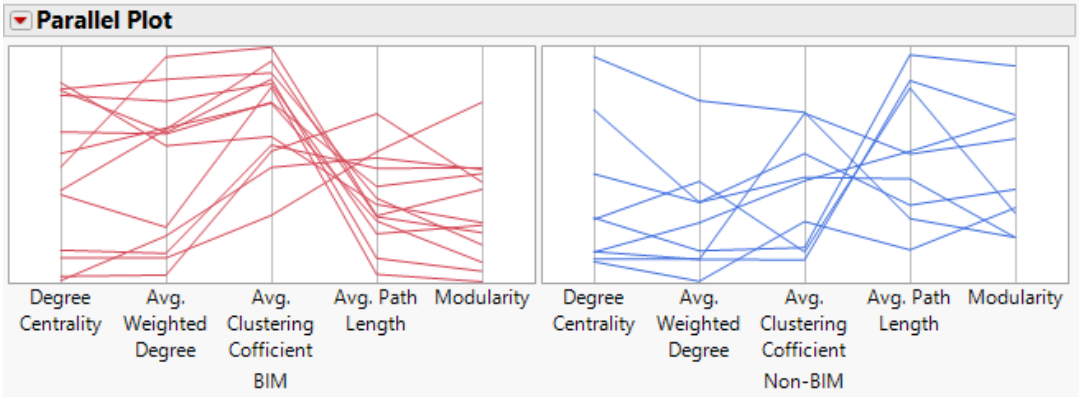


Figure 16 Properties Value parallel plot

From the discussion in phase 2 of the analysis, we found that for BIM projects degree centrality is higher, average clustering coefficient is higher, the average path length is shorter and modularity is lower.

Stage 3- With limited certainty for individual properties that can describe the difference between BIM and Non- BIM projects, we sought to understand the mutual relationship of the properties to identify the differences. To understand the impact of these properties, it is important to understand the relationship between the properties for BIM and Non- BIM projects. Hence, we studied the spread of co-relationship of the properties to investigate further.

From the scatterplot (fig. 18) of the properties, we can observe two different ellipses formed. This shows a difference in the mutual relationship of the properties for BIM and Non- BIM projects.

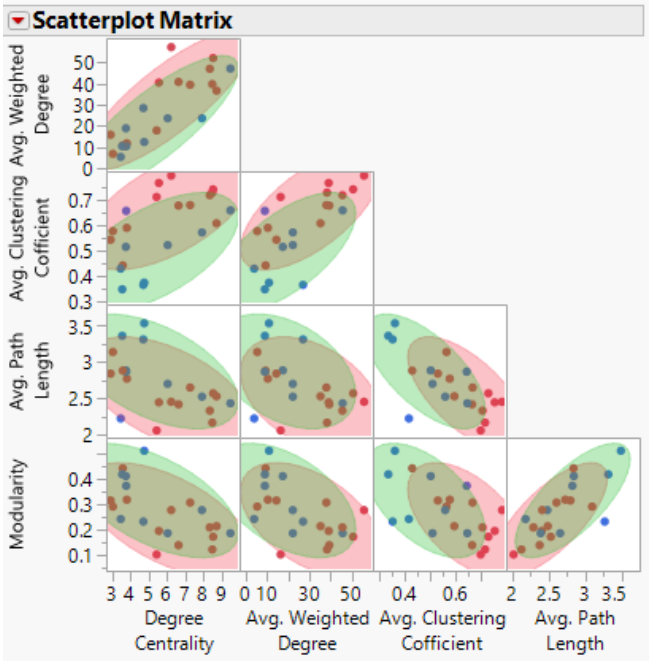


Figure 17 Co-relation of network Properties

Below are the table that shows the correlation of the network properties. Table 6 shows the correlation of BIM project network properties. Table 7 shows correlation of Non-BIM project network properties.

Table 6 Correlation of BIM project properties

Correlations

	Degree Centrality	Avg. Weighted Degree	Avg. Clustering Cofficient	Avg. Path Length	Modularity
Degree Centrality	1.0000	0.8128	0.6228	-0.6475	-0.6017
Avg. Weighted Degree	0.8128	1.0000	0.8036	-0.5509	-0.4591
Avg. Clustering Cofficient	0.6228	0.8036	1.0000	-0.7063	-0.7125
Avg. Path Length	-0.6475	-0.5509	-0.7063	1.0000	0.7957
Modularity	-0.6017	-0.4591	-0.7125	0.7957	1.0000

Table 7 Correlation of Non-BIM project properties

Correlations

	Degree Centrality	Avg. Weighted Degree	Avg. Clustering Cofficient	Avg. Path Length	Modularity
Degree Centrality	1.0000	0.8488	0.5525	-0.4106	-0.5392
Avg. Weighted Degree	0.8488	1.0000	0.4418	-0.2235	-0.5804
Avg. Clustering Cofficient	0.5525	0.4418	1.0000	-0.6161	-0.3495
Avg. Path Length	-0.4106	-0.2235	-0.6161	1.0000	0.6744
Modularity	-0.5392	-0.5804	-0.3495	0.6744	1.0000

The BIM projects have shown a higher level of correlation between properties than their Non- BIM counterparts. An attempt to modify a network in a manner to have favorable conditions for information flow is expected to show higher variations. This can be used to advantage by nudging the network to have better information flow. With higher correlation, the BIM projects are anticipated to show a higher response.

After determining the properties of individual project network, the objective was to understand the relationship between properties that differentiates BIM and Non-BIM projects. To determine the relationship of these properties with the usage of BIM in a project, it was important to determine which of these properties are contributing in establishing the differences between the projects. Since multiple network properties are contributing towards the overall network dynamics, we have to determine if the properties related to a project form

a consistent mutual relationship that can be classified into different groups. Hence, it is important to find out the dimension which could separate the data points. By this, we mean that there can be different directions of looking at the cluster of data (network properties) formed. Therefore, to determine the dimension in which the data is separable is the crux of the problem to identify if there is a difference in the network properties on the basis of usage of BIM in projects.

Stage 4- One approach is to look at the relationship of these properties with each other and determine the patterns in the relationship between properties. With multiple contributing properties, determining a consistent pattern for properties that can attribute towards clustering projects isn't the optimum and efficient process method. The reason being the relationship between the properties may vary for each project.

The other way to determine if there is a segregating dimension for the objects on the basis of multiple properties. The objective is to reduce the higher dimension space (multiple properties related to projects) in the form of canonical variables that can test the presence of the difference in overall network properties. Hence for this purpose discriminant analysis is used. Discriminant analysis is a reverse process where the segregating anticipated dimension is provided as an input. The relationship between properties is used to determine and predict if the data points are separable in the segregating dimension. In our scenario, the segregating dimension is the BIM and Non-BIM projects. Table 8 shows the results of the discriminant analysis.

On the basis of the results, it can be seen that the projects can be classified on the basis of the properties with a reliable degree of the accuracy. The result shows that the network parameters of the projects show a relationship with the usage or non-usage of BIM

in projects. This result validates our hypothesis that there is a difference in the communication network properties of a BIM and non-BIM project. The prediction number provides the evidence of differences in the properties of the network of a BIM and non- BIM project.

Table 8 Discriminant Analysis

Discriminant Scores

Row	Actual	SqDist(Actual)	Prob(Actual)	-Log(Prob)		Predicted	Prob(Pred)	Others
1	BIM	4.13122	0.5463	0.605		BIM	0.5463	Non-BIM 0.45
2	BIM	4.24610	0.1712	1.765	*	Non-BIM	0.8288	
3	Non-BIM	10.28445	0.8904	0.116		Non-BIM	0.8904	BIM 0.11
4	Non-BIM	8.75004	0.1719	1.761	*	BIM	0.8281	
5	BIM	10.29116	0.9659	0.035		BIM	0.9659	
6	BIM	3.36624	0.8940	0.112		BIM	0.8940	Non-BIM 0.11
7	BIM	6.72129	0.7857	0.241		BIM	0.7857	Non-BIM 0.21
8	BIM	2.61340	0.9804	0.020		BIM	0.9804	
9	Non-BIM	4.75141	0.4198	0.868	*	BIM	0.5802	
10	BIM	0.78768	0.8566	0.155		BIM	0.8566	Non-BIM 0.14
11	BIM	4.01244	0.5269	0.641		BIM	0.5269	Non-BIM 0.47
12	Non-BIM	1.86439	0.6471	0.435		Non-BIM	0.6471	BIM 0.35
13	Non-BIM	6.44077	0.8999	0.105		Non-BIM	0.8999	BIM 0.10
14	BIM	0.82870	0.7816	0.246		BIM	0.7816	Non-BIM 0.22
15	Non-BIM	4.56198	0.9673	0.033		Non-BIM	0.9673	
16	BIM	2.31859	0.8884	0.118		BIM	0.8884	Non-BIM 0.11
17	BIM	5.29470	0.2501	1.386	*	Non-BIM	0.7499	
18	Non-BIM	6.69046	0.9315	0.071		Non-BIM	0.9315	
19	Non-BIM	0.33057	0.8052	0.217		Non-BIM	0.8052	BIM 0.19
20	BIM	7.73332	0.9876	0.013		BIM	0.9876	
21	Non-BIM	2.70556	0.9567	0.044		Non-BIM	0.9567	
22	BIM	1.27551	0.8461	0.167		BIM	0.8461	Non-BIM 0.15

Table 9 Prediction Results

Actual BIM/ Non- BIM	Predicted BIM	Predicted Non-BIM
BIM	11	2
Non-BIM	2	7

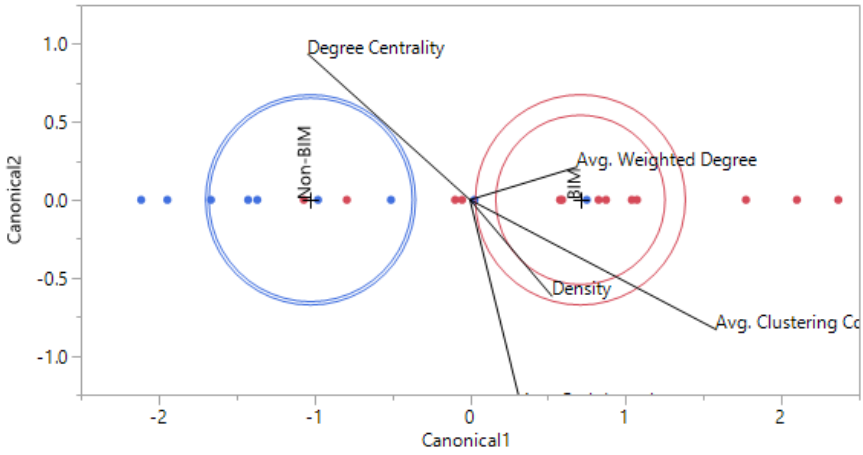


Figure 18 Canonical Value plot- Discriminant Analysis

In this analysis, we have covered properties that scale-free properties and hence these properties are the ones which are independent of the size of the network. The properties used to define the correlation are contingent upon the structure and type of the network.

We will now discuss the impact of properties that contributed to the difference in the communication network properties. To understand which parameters contribute towards the changes in the network of a BIM and non-BIM project, the correlation between parameters derived from the discriminant analysis is helpful.

From the output, we find that the clustering of projects can be defined by a linear combination of a number of properties. In our analysis, we try to understand the impact of the contributing factors such as average path length, modularity, centrality and average clustering coefficient.

The slope of the contributing variables with the canonical variables reflects the contribution of the property in segregating the project types. The slope of the dependence of the properties defines the contribution in changes. The more the axis of the contributing parameter is along the differentiating dimension (BIM vs Non- BIM), the more is its

relevance in contribution. The orthogonality of the contributing variable depicts less relevance.

The standardized scoring coefficients for the canonical variable are stated in the table 10.

Table 10 Standardized Scoring Coefficients

Standardized Scoring Coefficients

	Degree Centrality	Avg. Weighted Degree	Density	Avg. Clustering Cofficient	Avg. Path Length
Canon1	-0.693653	0.4599239	0.3508364	1.0559375	0.2216963

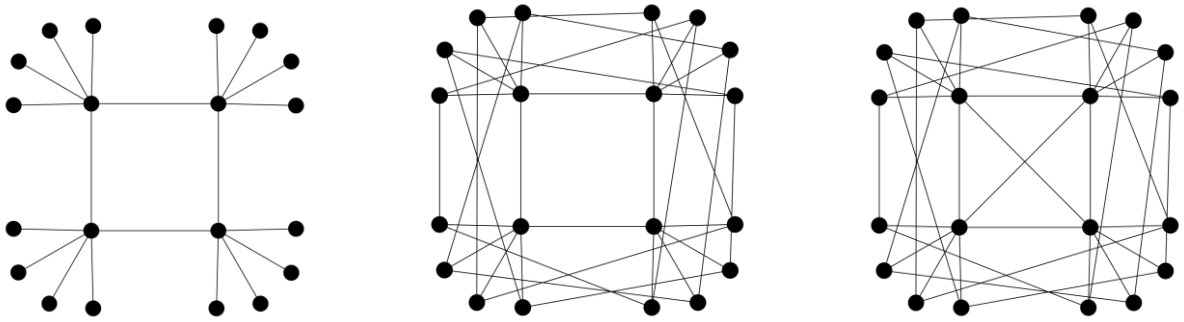
7. DISCUSSION AND CONCLUSIONS

The study has some very important outcomes and conclusions. The study structured a way to analyze the real-world communication network, the process of extracting the real world data and processing it to make it usable with the help of text analysis software, and the required clustering steps are few important contributions. Before this study, theoretical models were used to understand the communication network in AEC projects.

On the basis of discriminant analysis results, we have found that the BIM project networks are different from Non-BIM projects. The contributing properties on the basis of standardized scoring coefficients are average clustering coefficient, the degree of centrality, average weighted degree, density and average path length.

In order to quantify the benefits of usage, we need to understand the impact of variation of such properties on a network from the definition and practical perspective. In a simple expression, an efficient communication network is one with ease of transferring information.

Before delving into the significance of each property we try to understand how the structure of networks impacts these network properties. In figure 19 we have shown three simple network diagrams. The purpose of these three network diagrams to understand how the connections between the nodes impact the varies properties. These properties have been discussed in table 11. By comparing the network properties of these simple network we can understand what are the favorable conditions of each property from the perspective of the network communication.



(a) (b) (c)

Figure 19 Explanation of variation in properties

Table 11 Network properties of illustrative network diagrams shown in figure 19

	Degree of Centrality	Density	Modularity	Avg. Clustering Cofficient	Avg. Shortest path
A	2	0.105	0.55	0	2.653
B	3.7	0.195	0.339	0.016	2.289
C	3.8	0.2	0.332	0.029	2.179
More connected networks have	Higher	Higher	Lower	Higher	Lower

From the available data (table 12), it can be observed that the properties that impact the efficiency of communication, namely modularity, avg path length, degree centrality, density and average clustering coefficient have shown a favorable trend of more connected

networks for BIM projects. This study found trends of properties similar to stated in the study done on the basis of theoritical models by Al Hattab and Hamzeh (2015).

Table 12 Network Property Means

Count	BIM/Non-BIM	Degree Centrality	Avg. Weighted Degree	Density	Average Clustering Cofficient	Average Path Length	Modularity
13	BIM	6.21	32.08	0.063	0.66	2.55	0.23
9	Non-BIM	5.43	20.05	0.039	0.49	2.87	0.31

On an average, the degree of centrality is higher for BIM projects in comparison to Non- BIM projects. Average weighted degree signifies the number of connections of the nodes. A higher average weighted degree signifies on an average more connected nodes. More connections are helpful to have well-connected networks. BIM networks have shown a higher average weighted degree on an average, thus more connected networks. From the organization level perspective, a more connected network will be helpful in communicating the information throughout the network. An ease of spreading information within the network is a helpful condition for coordination between the individuals to complete a task. Average clustering coefficient shows the tendency of the nodes to cluster together. In real world scenarios, the clustering coefficient is higher. From the above comparison, we observed that the clustering coefficient is higher for BIM projects hence we can establish a relationship that the network properties are trending towards real world networks for BIM projects. An inclination towards real world scenarios depicts the helpful prod of technology towards real world.

A shorter average path length signifies that the flow of information from one node to other traverses shorter distance on an average. Shorter average path length entails faster communication of information between the network. With shorter average path length, the average time to communicate information between two nodes decreases given each nodes transfer the information at the same pace. Hence, a smaller value of average path length is helpful for the network. On an average, BIM projects have shown a shorter average path length.

Modularity shows the connection between the modules formed in the network. A higher number shows that the connections within the modules are a strong while between the modules are weak. Thus, information flow between the modules is limited for higher modularity networks. For BIM projects, the modularity number is lower. As per the definition of modularity, the lower the modularity number the more distributed a network is. A distributed network is a better performer and is found in natural social networks. Density depicts the ratio of connections present in the network to the maximum number of possible connections between the nodes. In a highly dense network, most of the networks will have direct connections to the other nodes. In this study, we found that on an average, the density is higher for BIM projects. This means that more nodes have direct connections with each other in comparison to Non- BIM projects. With more direct connections, the information flow will be easier.

Even with varying degree of communication connections within each network, a consistent pattern in the data has been found. This leads to a conclusion that BIM projects are more efficient in communicating information within the network which is helpful for the team to proceed efficiently. Thus, based on real world social network model we found that

the network properties are showing a trend to shift toward values of more connected networks in BIM projects.

7.1 Significance

A structured approach to extract, collect and segregate information to build communication networks is outlined in this research. This approach is required when a large database which contains information about multiple projects is utilized to build the communication network.

The research helped to determine the properties of the communication network in a project on the basis of unbiased information. This analysis helped to identify the key parameters that define the communication network. An understanding of key parameters helped to compare the differences in the communication network of a non-BIM project and a project which uses BIM. An analysis of differences contributed in quantifying the benefits of using BIM in AEC industry.

The research fulfilled a research gap by using real world data for depicting the communication network in a project. Thus, this research helped to validate the communication networks built on the basis of theoretical models.

The research approach will be helpful to devise methodologies that require a large database as a source to generate social networks in AEC industry. Intensive data analytics will be required to understand collaborative behaviors at the multi-company level.

7.2 Limitations

1) It would not be appropriate to state the realtionship found between the communication network properties and BIM & Non- BIM projects as absolute since other factors such as project delivery methods, type of projects, level of complexity, nature & modes of

communication also play an important role in the communication network properties. A causal relationship cannot be stated without controlling all the factors that can impact the communication network. With limited control over project delivery methods, type of projects, human factor, organizational behavior, modes of coomunication etc. only a probable trend can be identified.

2) This study focused on depicting a real-world network for the important individual (ex. Project Manager) in a project. The study can be extended to all the stakeholders in the project.

3) This study depicts the information flow as per the IT based communication channel (ex- email conversations, communication over applications) within the organization. Verbal communication forms a substantial part of the communication. The main limitation of this study is the inability to reflect the verbal communication within the organization. Thus, a set of information is not reflected in the analysis. Natural Language Processing (NLP) methodology can be utilized to depict the verbal communication in the form of a social network.

4) With significant use of information technology, platform based conversations are employed in projects. This study focused on utilizing sources that can be quantified and reflected in the social network analysis.

5) Input from the key project member (Project Manager) was used to determine the primary source of data. Relevant sources (ex- email conversation) can also be used to depict the communication network.

6) Email contents were not studied under this research.

This study ventured into a novel approach where real world data was analyzed. It provided a framework to create an automated process to extract the connections and segregate them on a project basis with the help of text clustering. With the help of plugins the segregated data was imported and analyzed in social network analysis software.

7.3 Future Works

In future works, researchers suggest that in order to specifically identify the impact of BIM and non- BIM, the study should be set up from the start of the projects. The guidelines that help to contain the variability of other parameters should be set up. An experiment set up in this manner, repeated over a number of projects should be helpful in deciphering the possible correlation of network properties. While performing the analysis, the researcher realized a possible alternative to provide definite percentage improvement number is by performing temporal analysis of the information flow. Analysis of the information flow may directly represent the improvement of the communication network. Another possible usage of this methodology to perform a process mapping using real world action rate and simulating it in agent-based modeling software can help to understand the percentage efficiency and the bottlenecks in the project. Thus, the structures derived from this methodology can be used to build the framework of process mapping.

The entire process can be developed as an application which can use by project executives to oversee various projects. The other possible use of this approach can be to understand the resource allocation within projects. This process can be utilized to perform temporal analysis of the projects to determine the utility of various resources during different phases of the projects.

Also, a similar analysis can be performed for various stakeholders i.e. design team, coordination team, operations management team. The insights should be helpful to understand the flow of information within the teams and networks.

Another application can be to understand the change in structure of the teams during different phases of the projects. This will lead to a better understanding of the contributing resources during different phases of the project. A probable application can be for resource allocation within different projects. Parameters based on communication can be devised that objectively define the utilization of a resource. Studied in this manner, over or under utilization of resource can be monitored. This can be helpful to increase efficiency of the project teams. A more detailed study on an organization level with a structured approach can help to build the operation optimization tools. Thus, further research in this area can be useful for sectors where humans are the asset for the companies.

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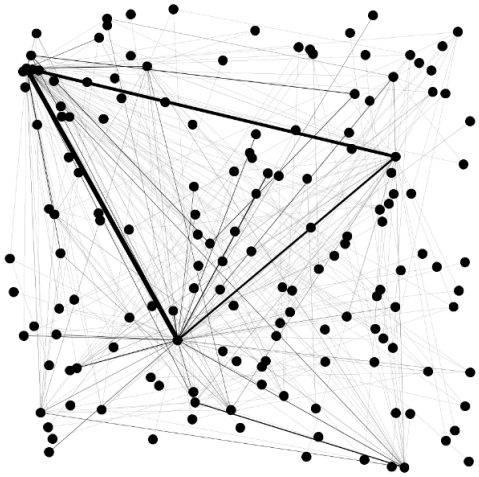
APPENDIX 1. PROJECT NETWORK DIAGRAMS

The project diagrams are based on the collected email log for the 22 projects. Read these with the network metrics provided in the table 5.

Project 1



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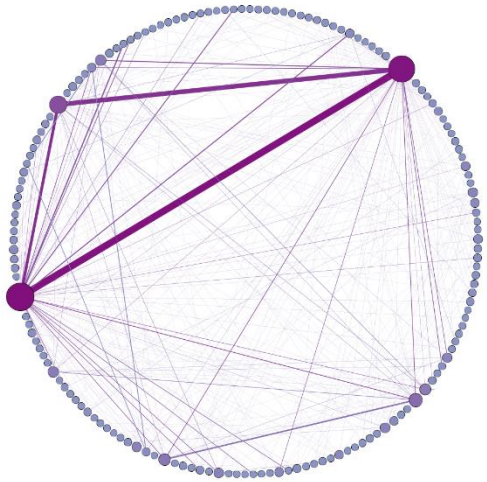

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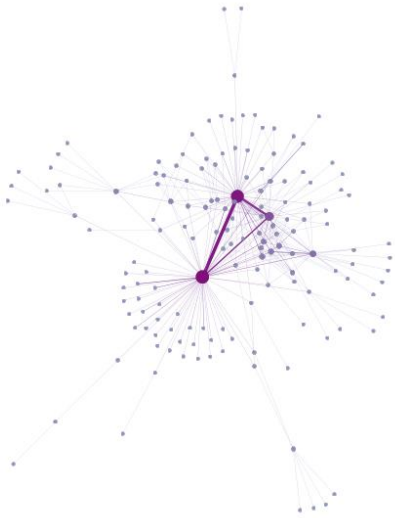

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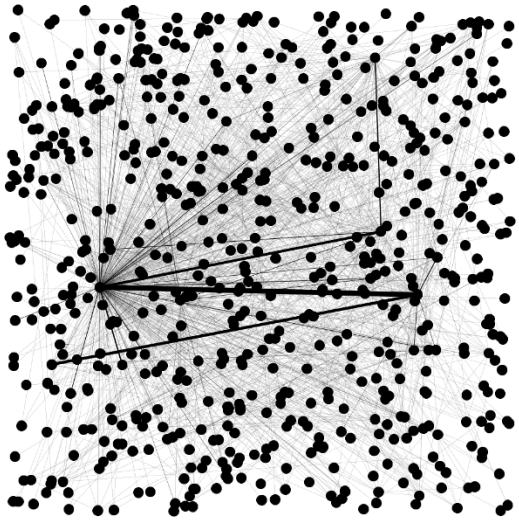

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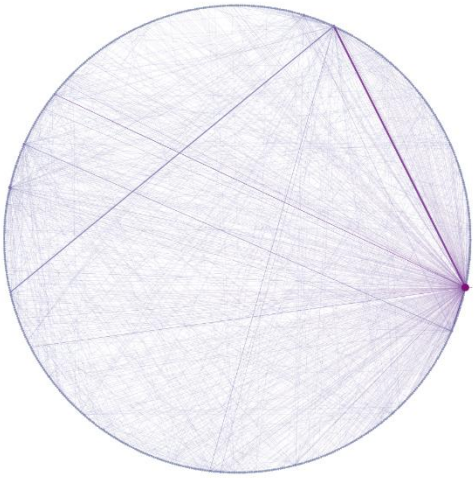

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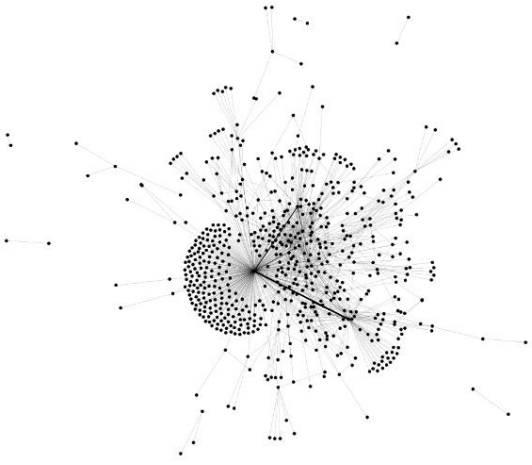

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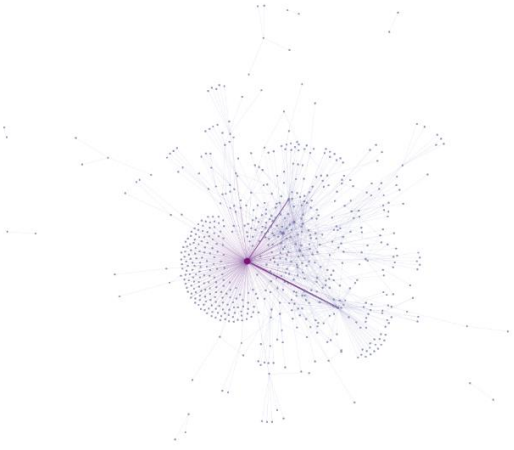

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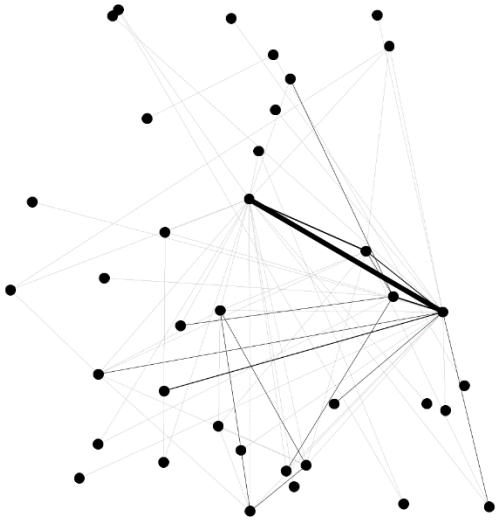

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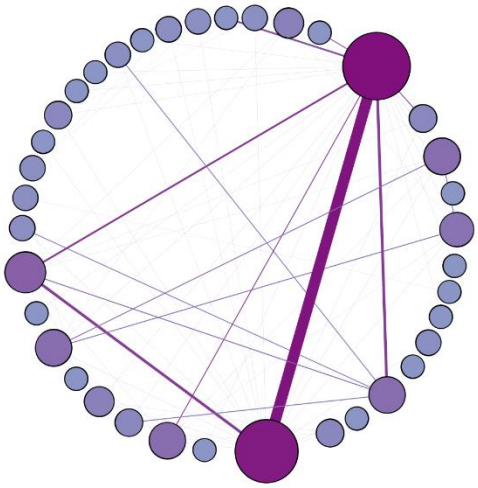

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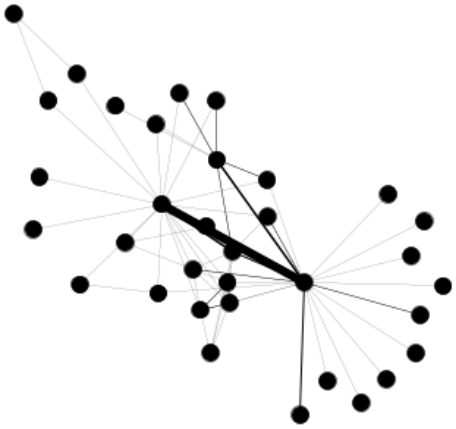

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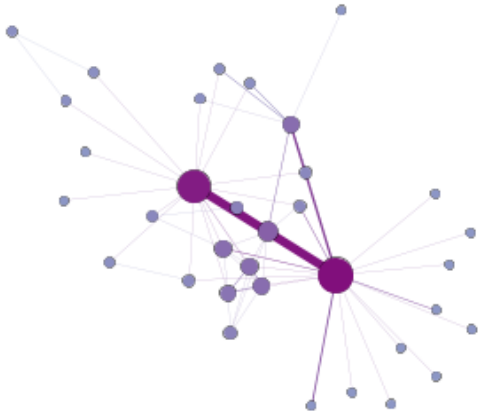

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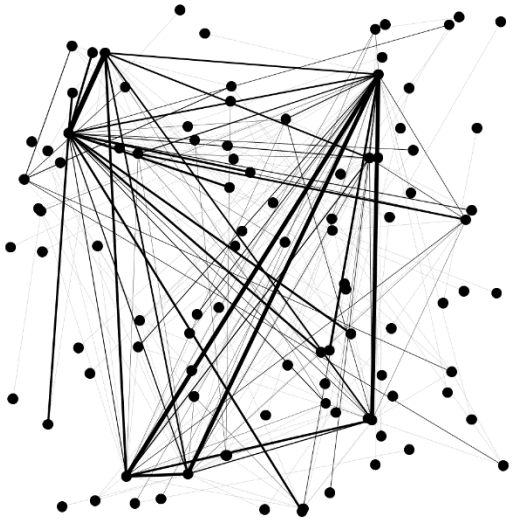

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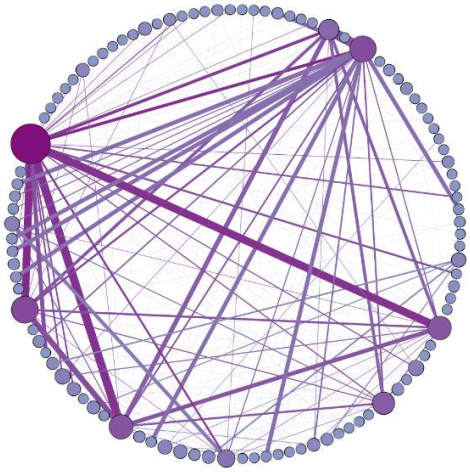

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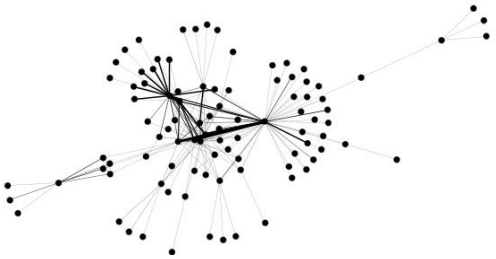

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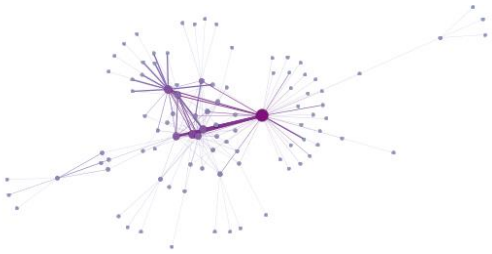

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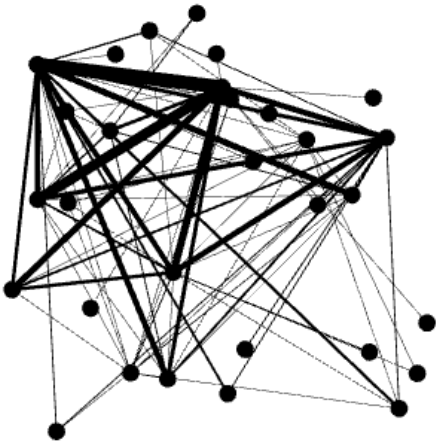

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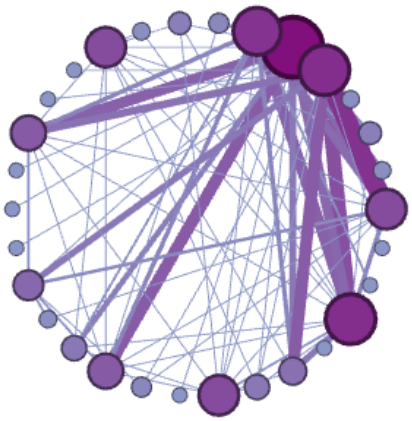

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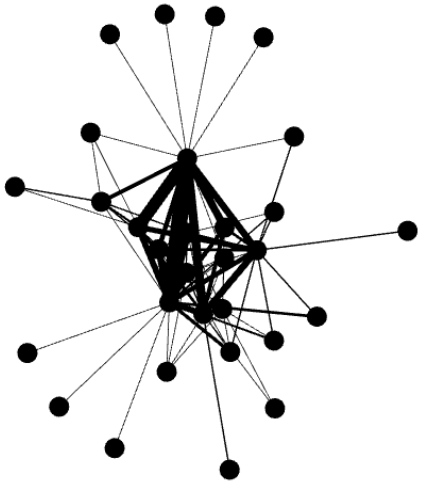

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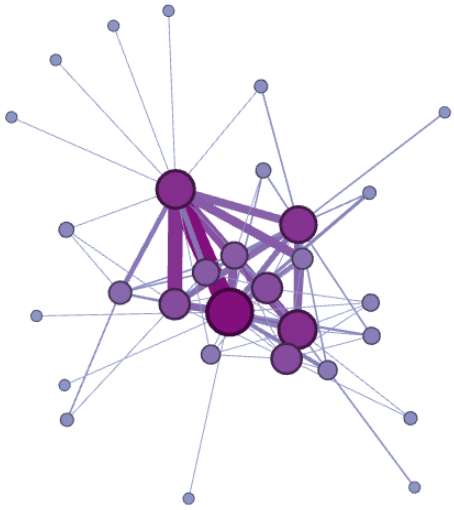

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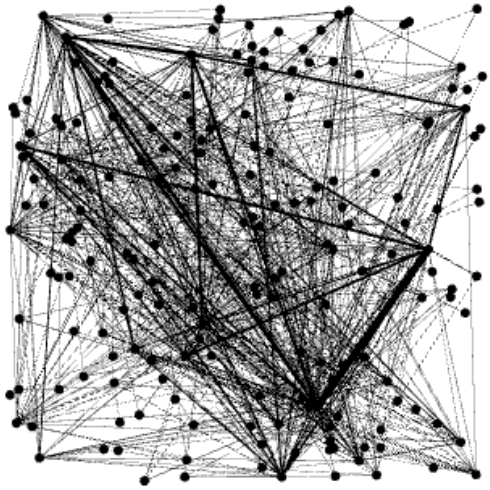

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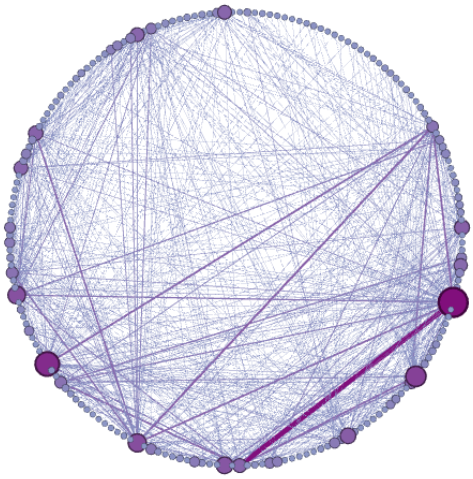

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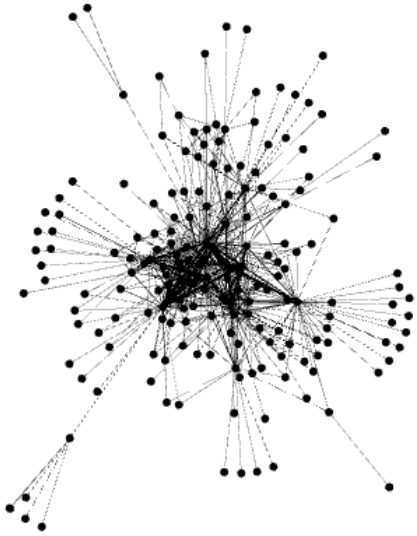

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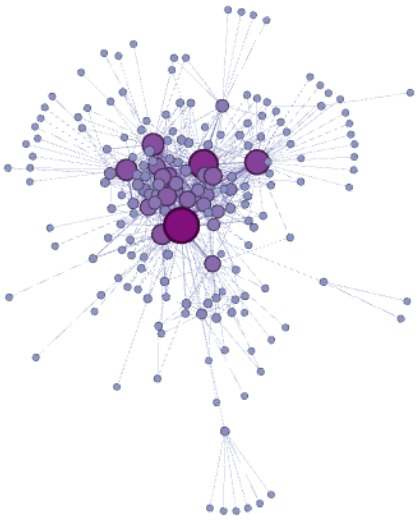

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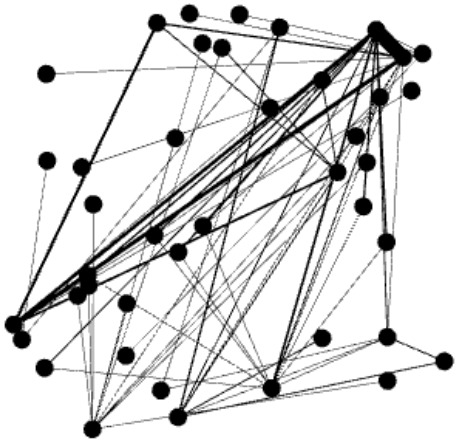

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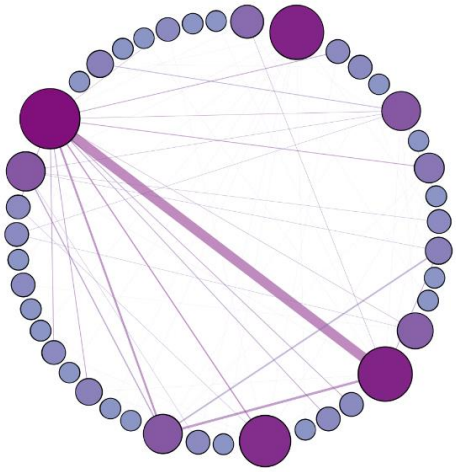

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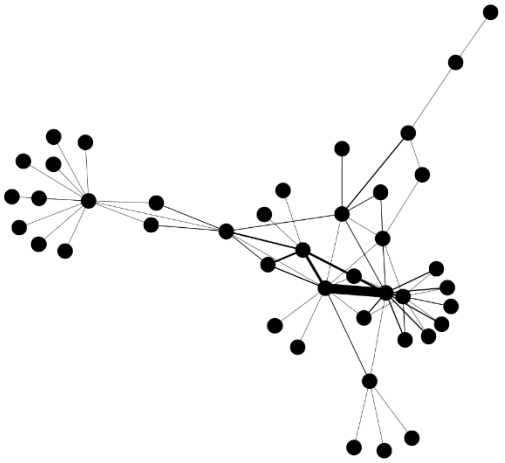

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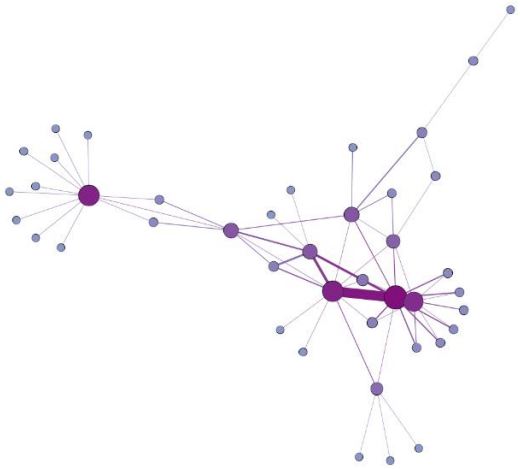

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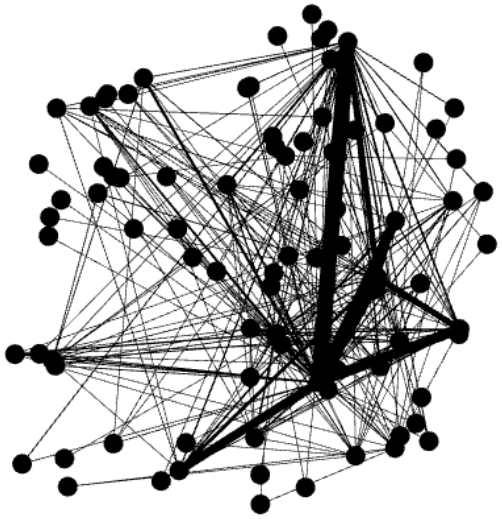

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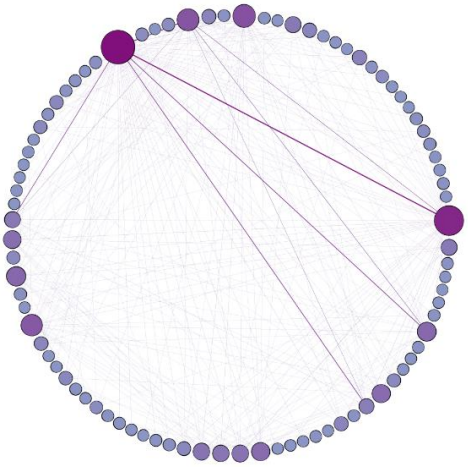

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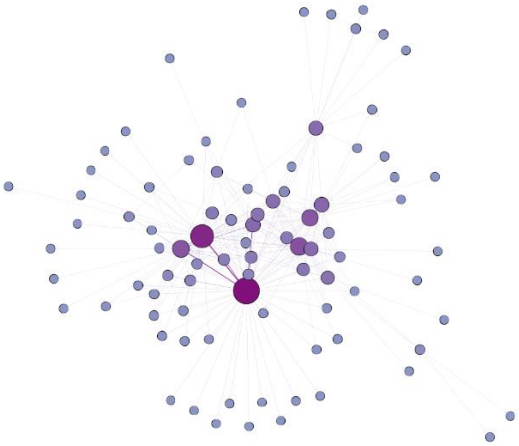
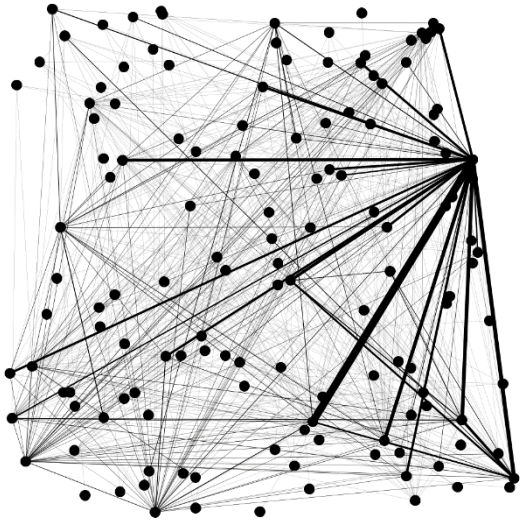


Yifan Hu Propotional with node sizes

Project 9



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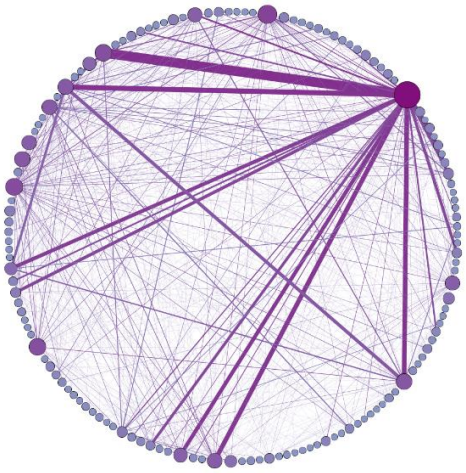

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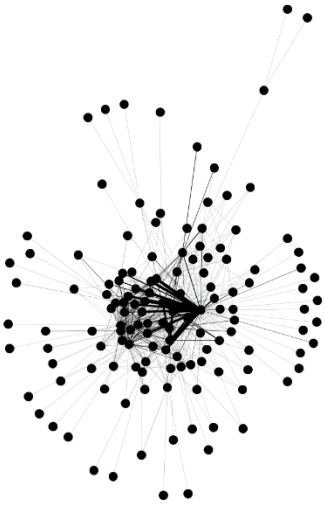

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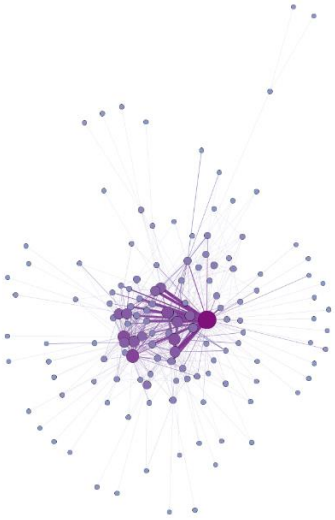

Yifan Hu Propotional with node sizes

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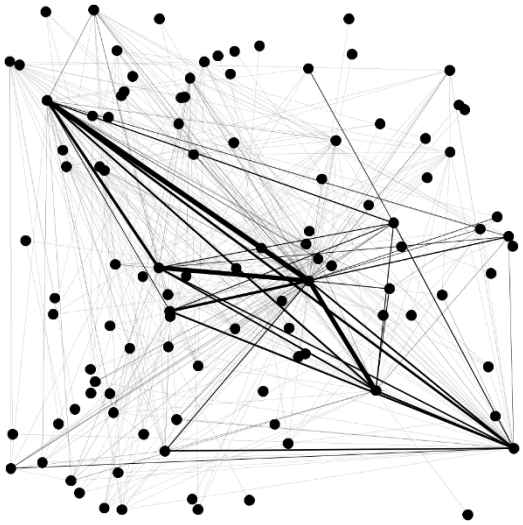

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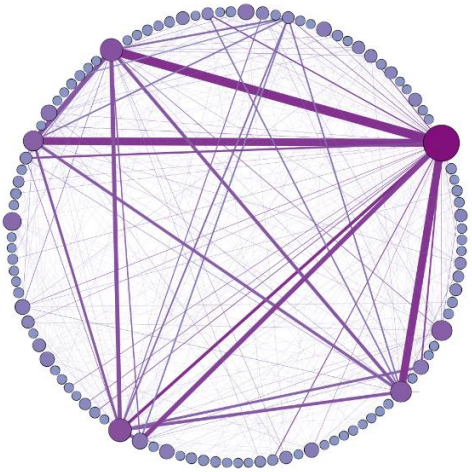

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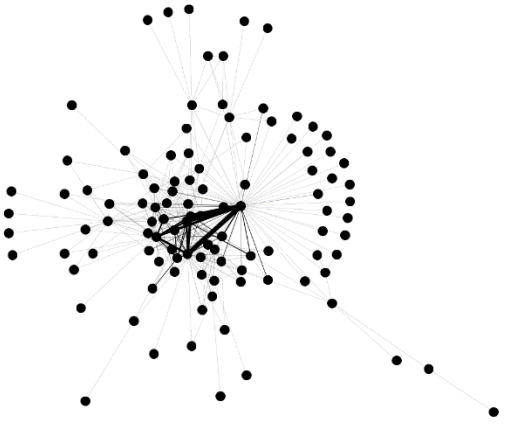

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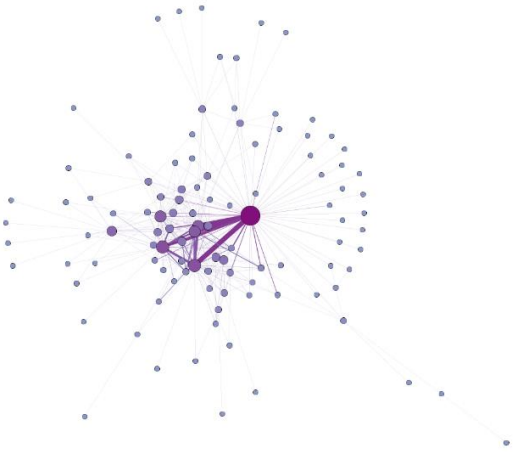

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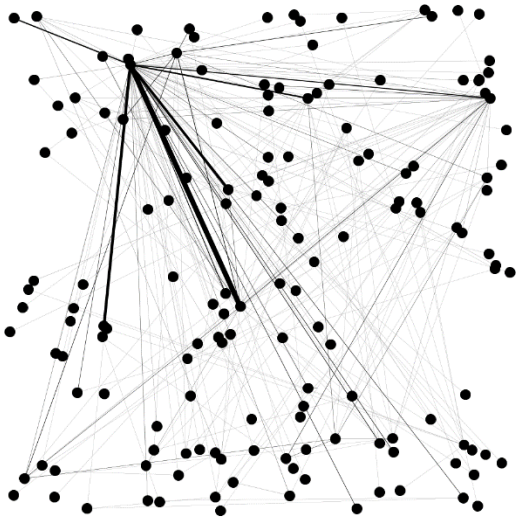

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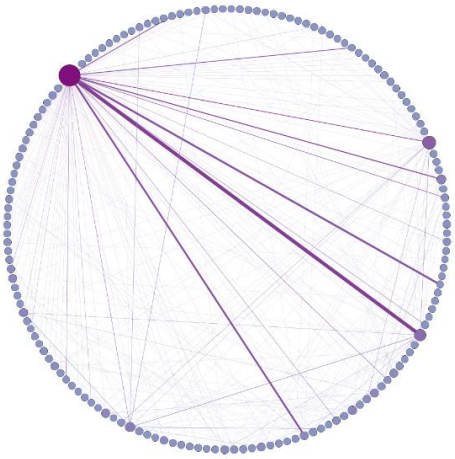

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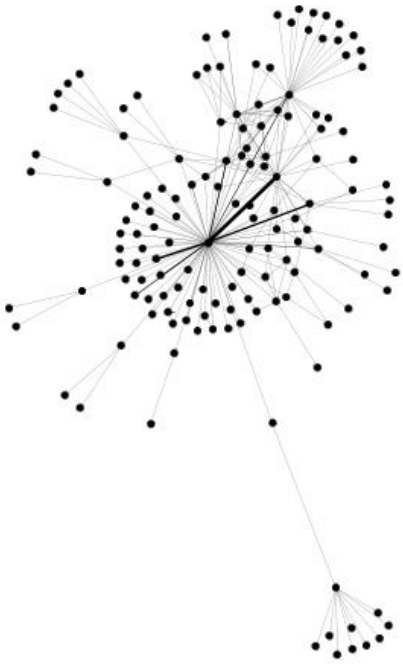

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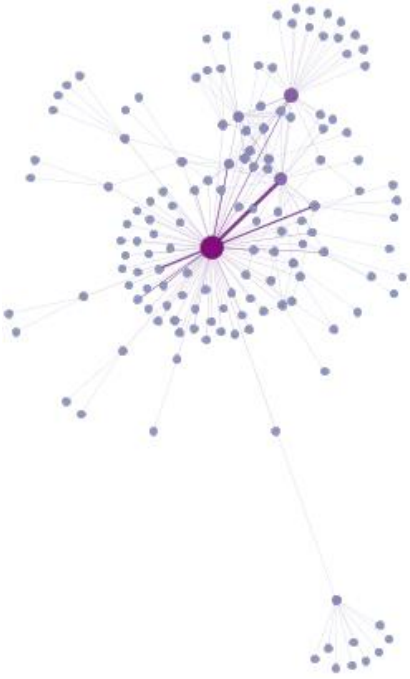
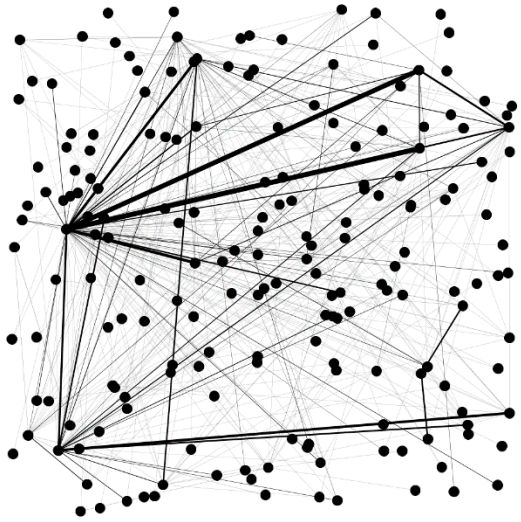


Yifan Hu Propotional with node sizes

Project 12



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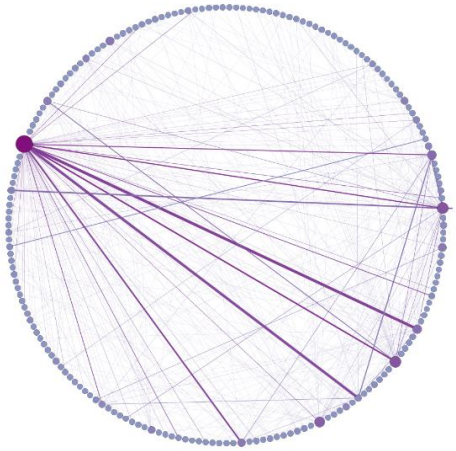

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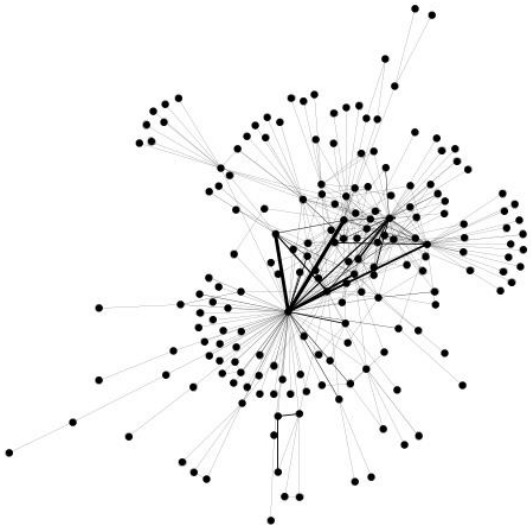

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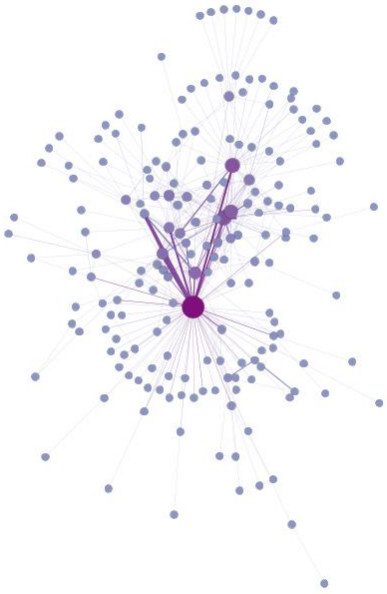
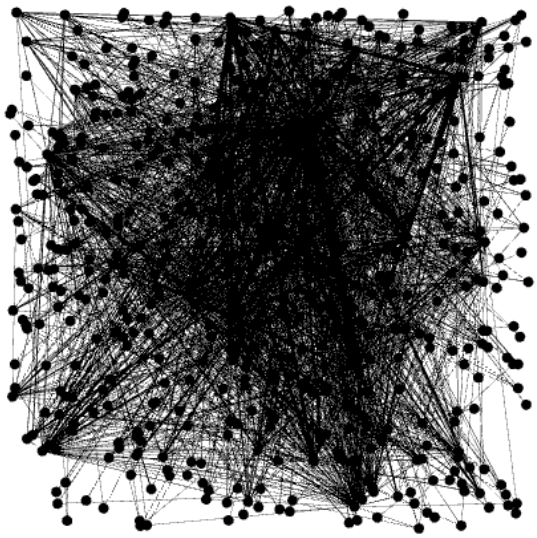
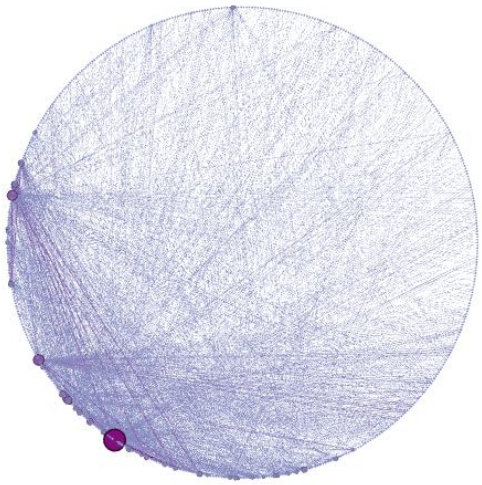


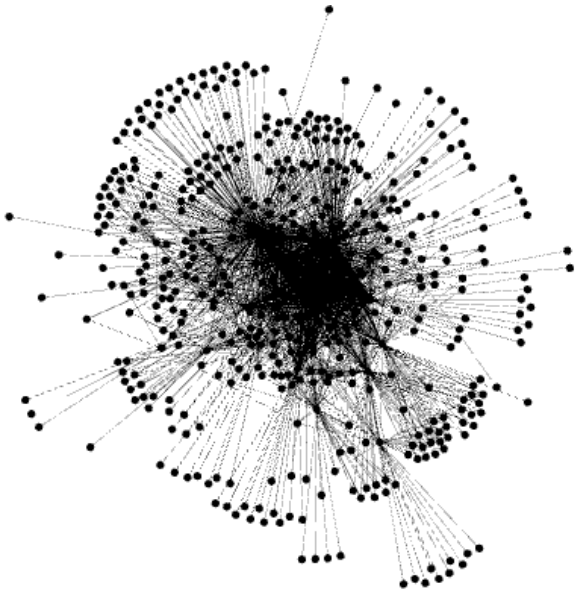
Yifan Hu Propotional with node sizes



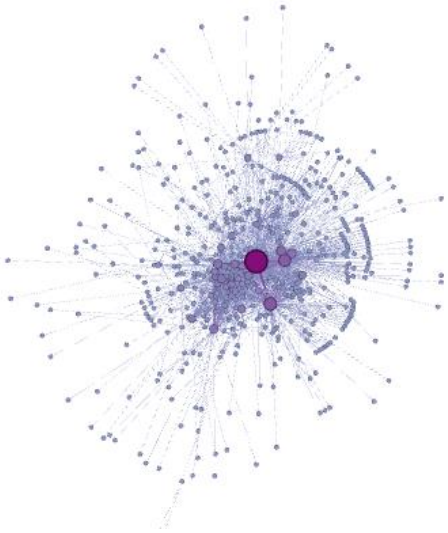
a) Random Layout



b) Circular Layout

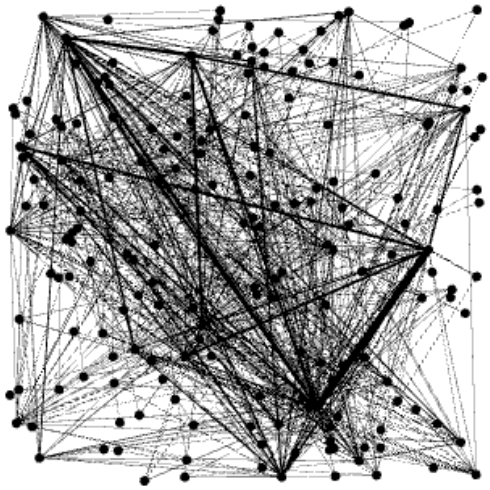


c) Yifan hu



d) Yifan Hu Propotional with node sizes

Project 14



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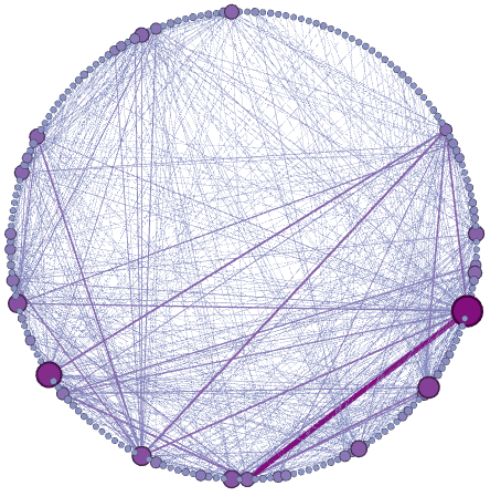

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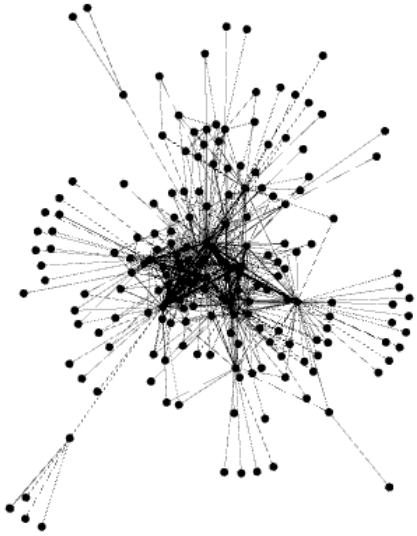
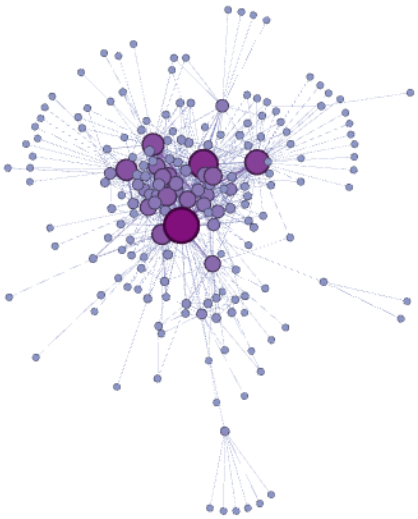
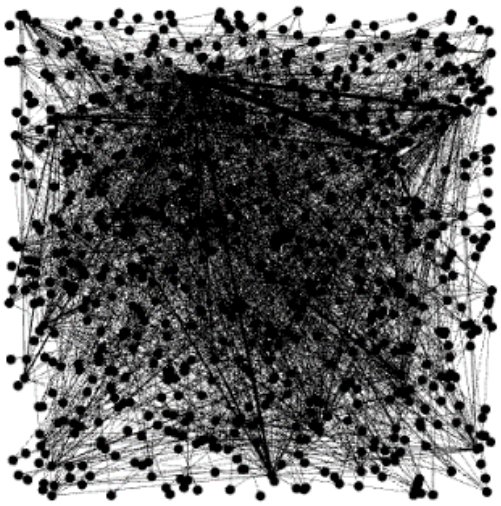


Yifan hu



Yifan Hu Propotional with node sizes

Project 15



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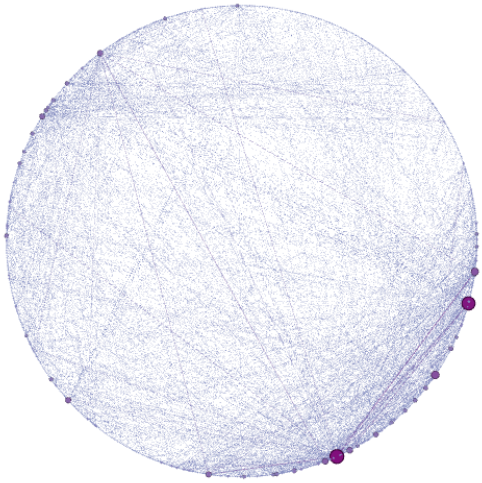
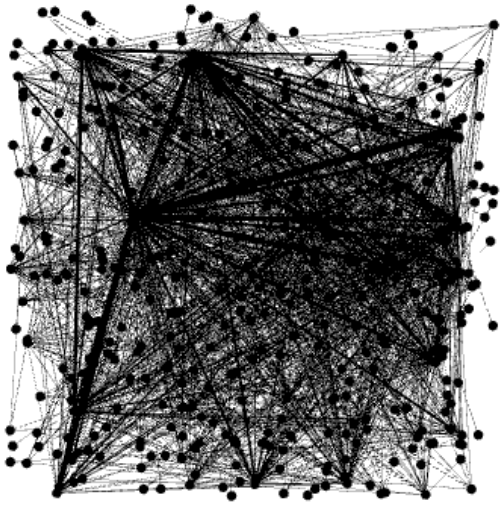


Circular Layout

Yifan hu

Yifan Hu Propotional with node sizes

Project 16



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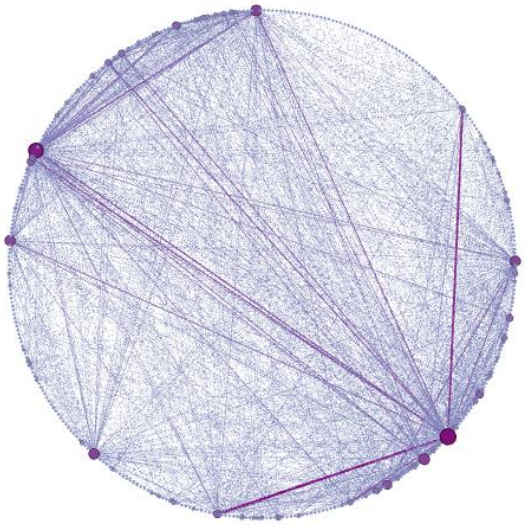
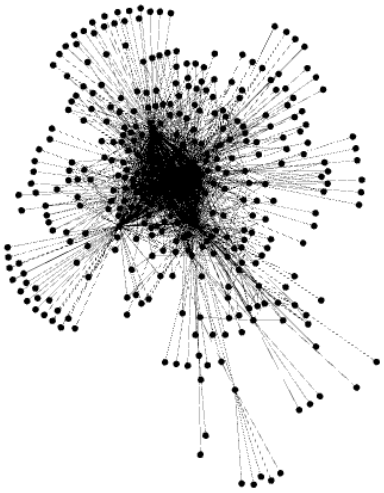
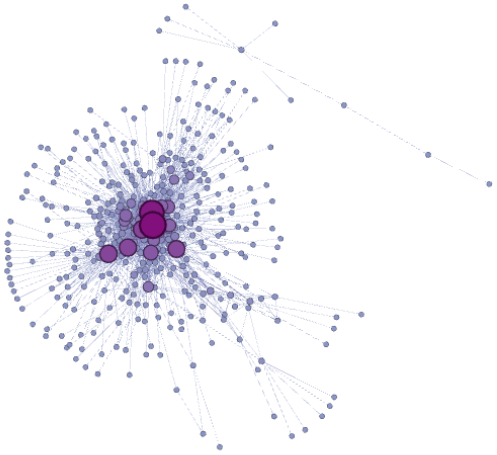


Circular Layout

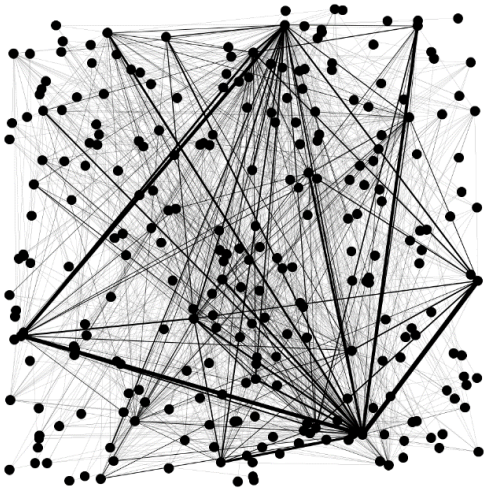


Yifan hu



Yifan Hu Propotional with node sizes

Project 17



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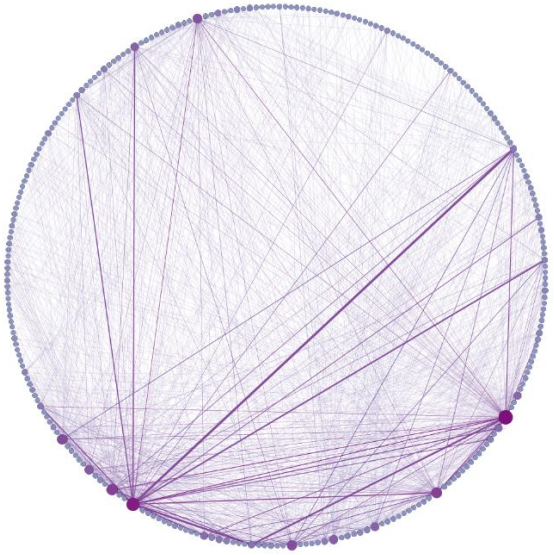
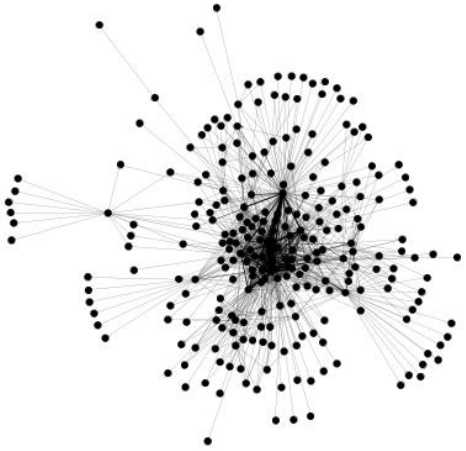
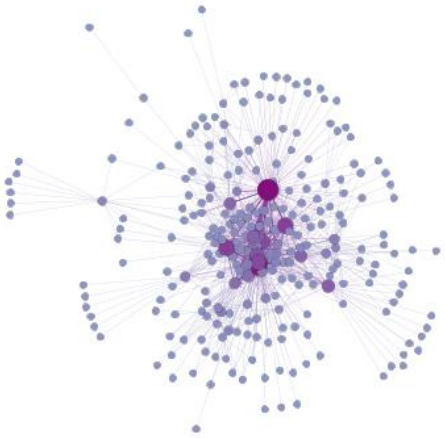


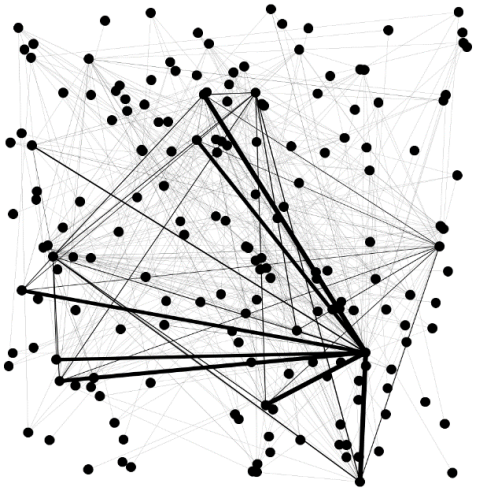
Circular Layout



Yifan hu



Yifan Hu Propotional with node sizes



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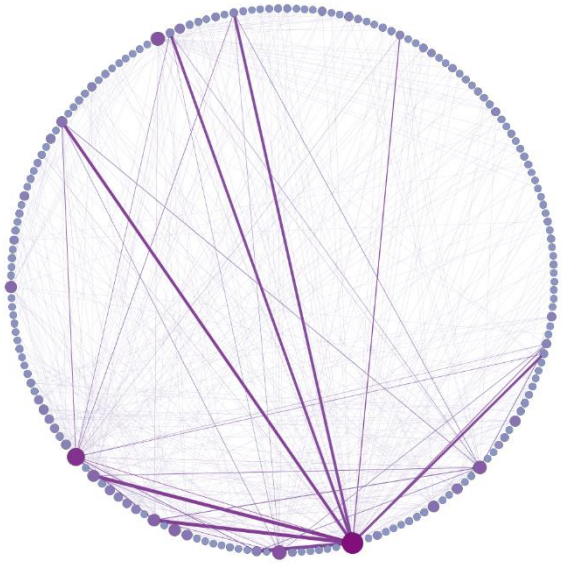
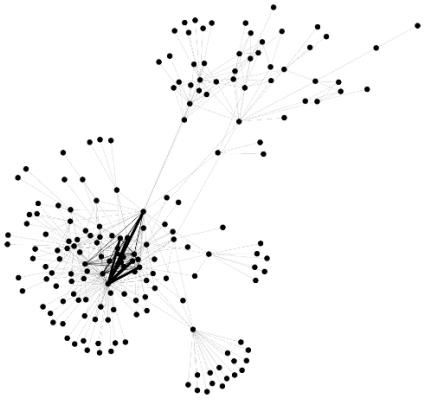
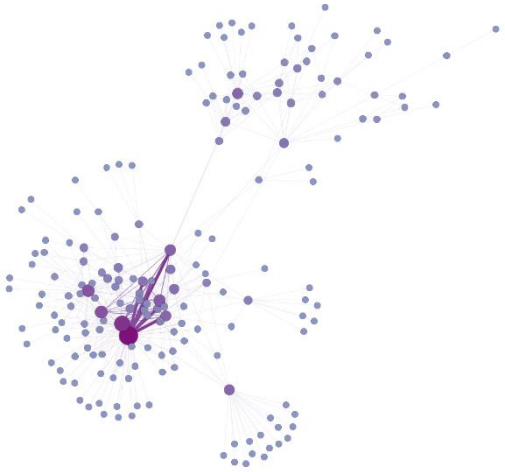


Circular Layout

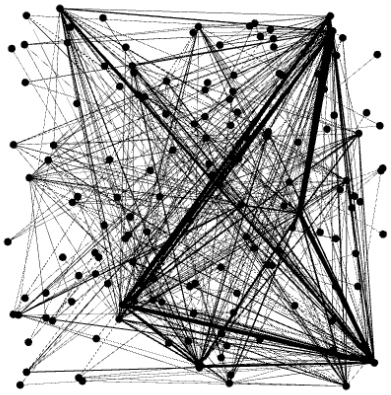


Yifan hu



Yifan Hu Propotional with node sizes

Project 19



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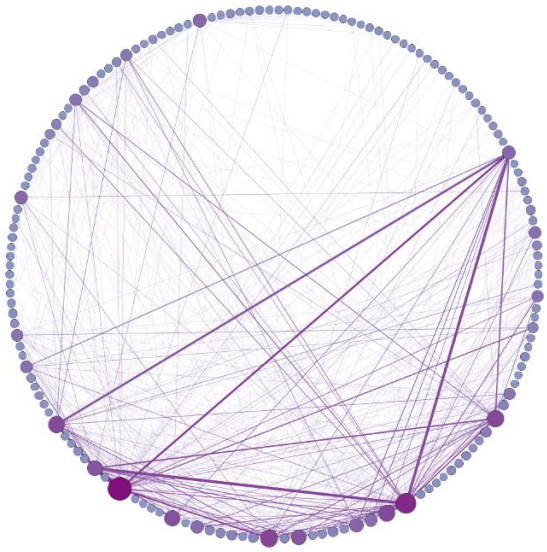
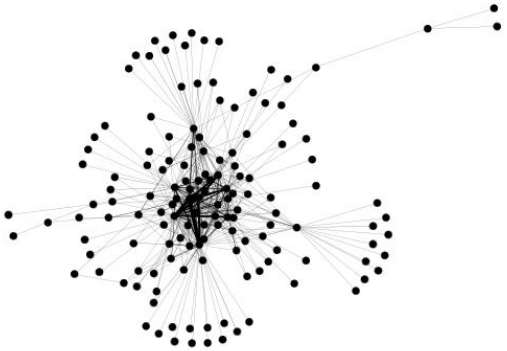
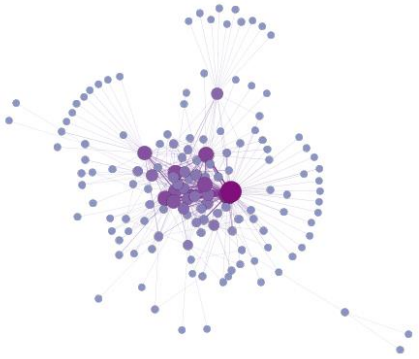


Circular Layout

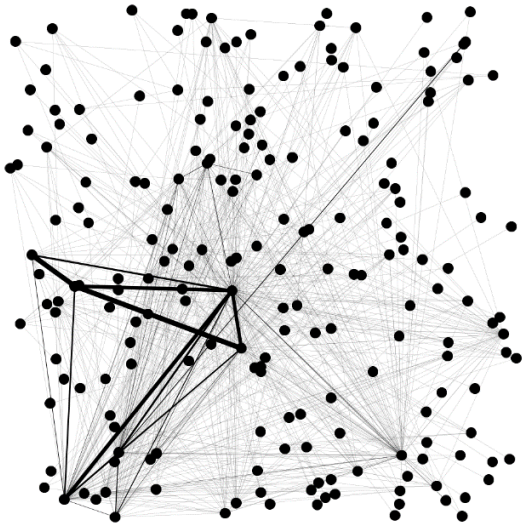


Yifan hu

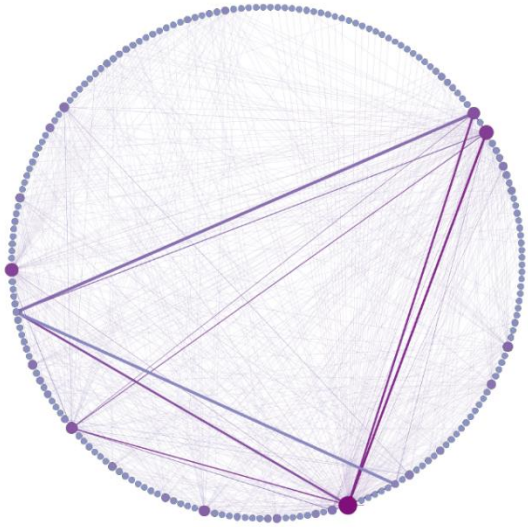


Yifan Hu Propotional with node sizes

Project 20



Random Layout



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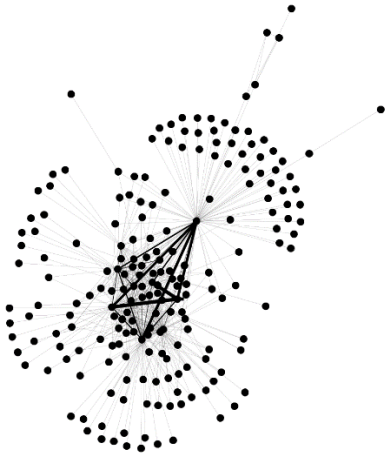
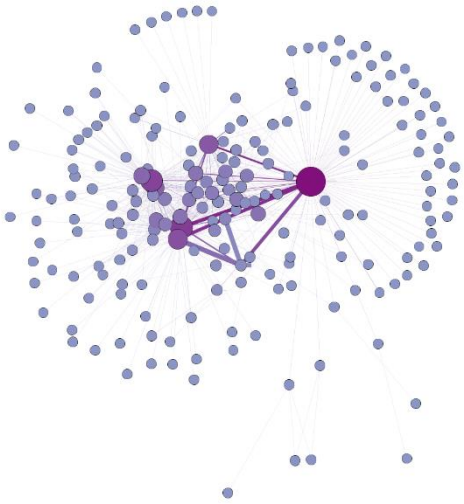
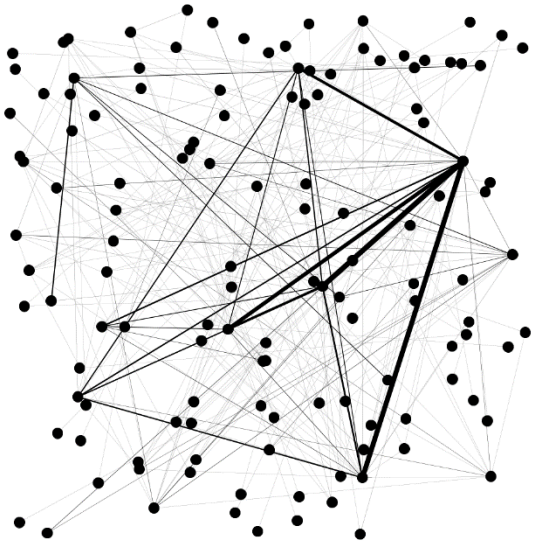


Yifan hu



Yifan Hu Propotional with node sizes

Project 21



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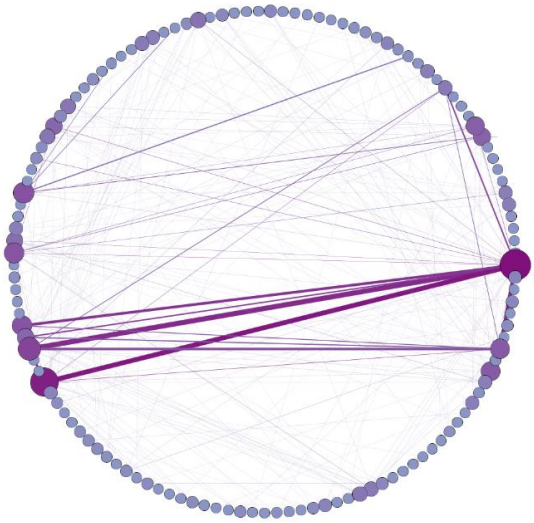
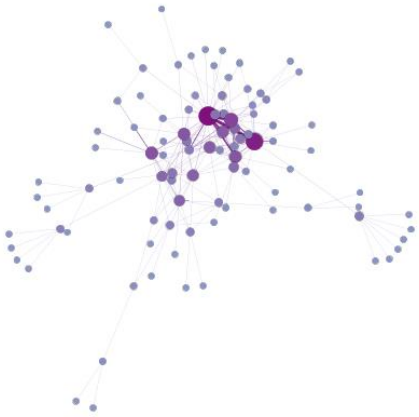


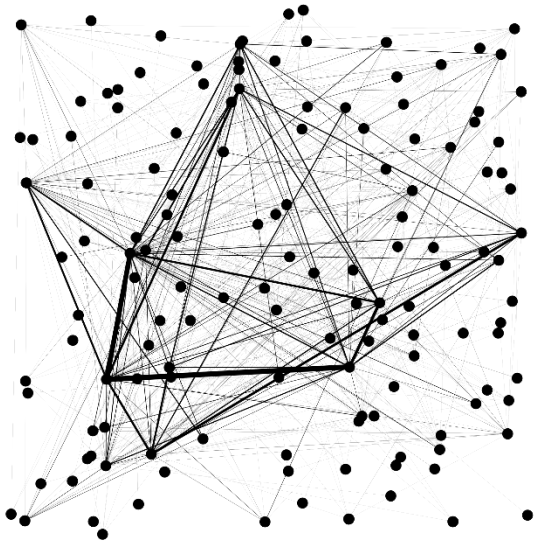
Circular Layout

Yifan hu



Yifan Hu Propotional with node sizes

Project 22



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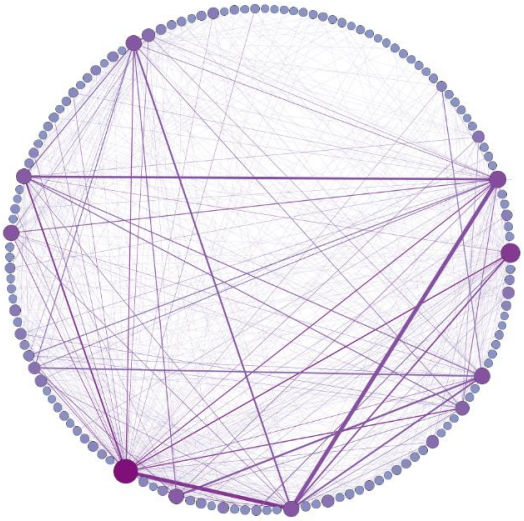
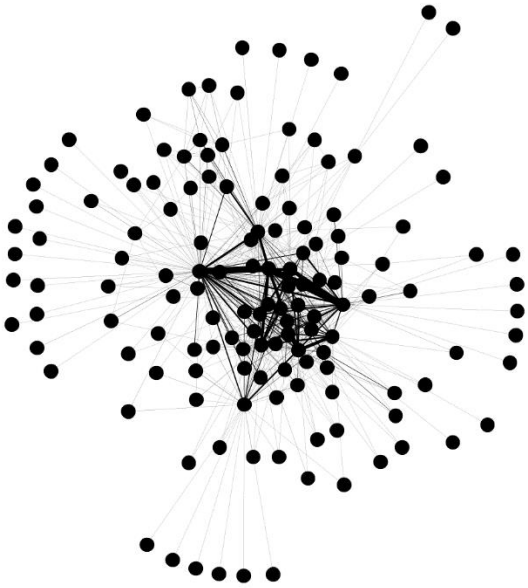
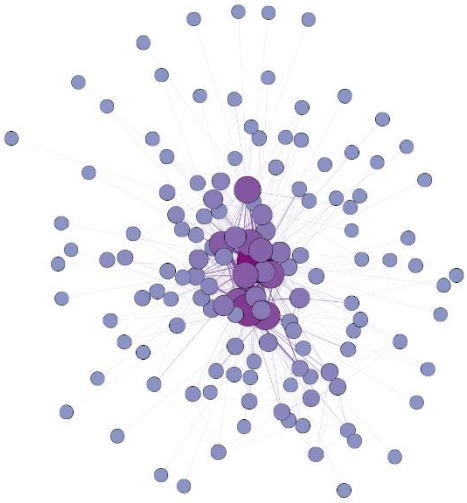


Circular Layout



Yifan hu



Yifan Hu Propotional with node sizes

APPENDIX 2. IRB APPROVAL

DIVISION OF RESEARCH

TEXAS A&M UNIVERSITY

DATE: September 06, 2016

MEMORANDUM

TO: Jing Du
TAMU - Texas A&M University - Not Specified

FROM: Dr. David Martin
Chair, TAMU IRB

SUBJECT: Expedited Approval

Study Number: IRB2016-0541D

Title: COMMUNICATION NETWORK ANALYSIS TO COMPARE BIM AND NON-BIM APPROACH IN THE AEC INDUSTRY

Date of Determination:

Approval Date: 09/06/2016

Continuing Review Due: 08/01/2017

Expiration Date: 09/01/2017

Documents Reviewed and Approved: Only IRB-stamped approved versions of study materials (e.g., consent forms, recruitment materials, and questionnaires) can be distributed to human participants. Please log into iRIS to download the stamped, approved version of all study materials. If you are unable to locate the stamped version in iRIS, please contact the iRIS Support Team at 979.845.4969 or the IRB liaison assigned to your area.

Submission Components			
Study Document			
Title	Version Number	Version Date	Outcome
Informed Consent	Version 1.1	08/17/2016	Approved
Informed Consent	Version 1.0	08/17/2016	Void
HumanResearch	Version 1.0	08/03/2016	Approved

Document of Consent: Written consent in accordance with 45 CF 46.116/ 21 CFR 50.27

Comments:

- This study is approved for 50 participants.
- This IRB study application has been reviewed and approved by the IRB. Research may begin on the approval date stated above.
- Research is to be conducted according to the study application approved by the IRB prior to implementation.
- Any future correspondence should include the IRB study number and the study title.

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